NUTRITION OF CONTAINER GROWN PLANTS

WITH EMPHASIS ON THE PROTEACEAE

A THESIS SUBMITTED FOR THE DEGREE

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Frontispiece

The comparative growth response of *Grevillea rosmarinifolia* - the main test species, in three different treatments:

left to right

	Added Nutrients (g/m^3)		
	High N & P	High N & K	High P & K
N	450	450	45
P	300	30	300
K	25	250	250

Left - severe P toxicity in the presence of high N

Middle - good growth response to added N.

Right - N deficiency but no P toxicity despite high added P levels.

CERTIFICATE

I hereby certify that the work reported in this thesis was carried out by the candidate under my supervision and that he planned, executed and described the material which is now submitted.

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(Supervisor)

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SUMMARY

1) Supplying soilless media with Osmocote (26% N) and other short term fertilisers proved to be a satisfactory method of studying the comparative nutrition of a wide range of container grown nursery plants using factorial experiments incorporating N, P, K and lime. Nutrient response surfaces were obtained using a central composite incomplete block design.

2) Most proteaceous shrubs were intolerant of high P levels due to excessive luxury consumption resulting in toxic foliar nutrient levels, especially in the presence of high N.

3) Phosphorus sensitivity in plants appeared to correspond with the soil nutrient levels in their native habitat. This applied to species studied in the 2 main sub-families in the Proteaceae while similar findings were indicated for other Australian genera.

4) A range of optimum N requirements in the Proteaceae was found - lowest needs for *Protea* which also had the greatest tolerance of very low fertiliser additions, compared to *Grevillea robusta* with much higher N requirements and strong foliage growth inhibition if nutrient levels are very low.

5) Proteoid root growth on *Grevillea rosmarinifolia* only occurred at low nutrient levels and was not required for satisfactory foliage growth of container grown plants.

6) Pot plants and seedlings, especially tomato, responded strongly to N and often there were positive NK interactions influencing foliage growth. Lime requirements were studied and in erica increasing lime rates depressed foliage growth.

7) Comparative nutrition studies indicate that general or broad spectrum container media may be unsuitable for some groups of nursery plants and that they could be replaced by potting mixes designed to meet the widely differing needs of the species often grown. The number of specialist mixes would depend on the range of plants and be governed by management considerations.

CHAPTER 1

LITERATURE REVIEW

World Distribution and Evolution of the Proteaceae

Johnson and Briggs (1974) stated that the first study of the Proteaceae was presented by Robert Brown to the Linnean Society of London in 1809. Several workers have studied the taxonomy of the family including Johnson and Briggs (1963) who made a complete revision of the genera in 1974. They stated that the family consisted of 75 genera grouped into 3 sub-families, 20 tribes and 20 sub-tribes. Hutchinson (1967) had previously classified the family into the Grevilleoideae and Persoonioideae but the former 2 workers (Johnson and Briggs 1974) have added an additional sub-family. The most important genera grown in New Zealand nurseries are classified in this system with *Toronia* added:-

Sub-Family:	GREVILLEOIDEAE				
Tribe:	KNIGHTIEAE	EMBOTHRIEAE	GREVILLEEAE	MACADAMIEAE	BANKSIEAE
Sub-Tribe:	Knightiinae	Embothriinae	-	Macadamieae	Banksieae
Genera:	*Knightia*	*Embothrium*	*Grevillea*	*Macadamia*	*Banksia*
		Telopea	*Hakea*		*Dryandra*

Sub-Family:	PERSOONIOIDEAE	PROTEOIDEAE	
Tribe:	PERSOONIEAE	PROTEEAE	
Sub-tribe:	Persooniinae	Aulacinae	Proteinae
Genera:	*Toronia*	*Leucadendron*	*Leucospermum*
			Protea

Proteaceae is an ancient family and its origin remains one of the major phylogenetic mysteries. Johnson and Briggs (1963) consider that proto-proteaceous plants existed before the Upper Cretaceous in tropical and sub-tropical rain forest. By the end of the Upper Cretaceous, the Proteaceae had evolved and distribution was perhaps almost cosmopolitan, although evidence for this is rather inconclusive (Rao, 1971). Darlington (1965) believes the Proteaceae developed in the tropics and migrated southwards during a long period of widespread warm, moist conditions. Later, during a cold climate, they became extinct in Antarctica and survived only in more northerly refugia, from where they spread southwards again with climatic improvement.

Burbidge (1960) discussed the evidence for an Antarctic origin and pointed out that the paucity of Proteaceae in New Zealand is unusual if they originated in Antarctica. Rao (1971) believes that Australia was the home of the Proteaceae which originated in mountainous rain forests and later spread into the lowlands. This is supported by the fact that all 5 sub-families and most tribes are represented in that country. Separation of ancestral stocks occurred early during angiosperm development with subsequent independent speciation in the different land masses.

Many workers have discussed the past and present distribution including Sleumer (1954), Burbidge (1960) and most recently Johnson and Briggs (1974). The family is predominantly a Southern Hemisphere one with centres in South America, South Africa and the Australasian super-region (including S. and E. Asia and Melanesia). The latter has by far the greatest diversity with representatives of all 5 subfamilies; 34 of the 40 genera of Grevilleoideae occur in, and 30 are confined to, the region. A noteworthy exception is the subtribe Proteinae which is absent from the region and occurs only in South Africa where there are 13 genera which are all endemic. Australia itself has 45 (35 endemic) of the 75 genera in the family including 28 (18 endemic) of the 40 in the Grevilleoideae.

South Africa and Australia have no genera in common. South Africa contains only 2 genera outside the Proteoideae, both of which are endemic and belong in the Macadamieae tribe of Grevilleoideae (Johnson and Briggs 1974). Although the Australian flora has a strong affinity with that of South America there is little evidence suggesting a similar relationship with the flora of Southern Africa (Burbidge, 1960). In the genus *Orites* for example, there are two species in South America and eight in Eastern Australia and Tasmania (Rao, 1971). The two New Zealand proteaceous genera (*Knightia* and *Toronia*) are absent from South Africa and South America, with *Knightia* being confined to New Zealand and New Caledonia.

The phytogeographic history of the Proteaceae was discussed by Johnson and Briggs (1974) who reviewed the significance of modern theories on plate tectonics compared to the old hypothesis of continental drift in terms of the distribution and ecology of the early Proteaceae. The present ecological distribution and recent reasons for that distribution is of greater relevance to nursery container culture rather than the early history.

Distribution and Habitat in Australia

The ecology of the Proteaceae in Australia is of major importance in this study because soil fertility and nutrition have played a major role in the establishment and persistence of these plant communities. The family is most prolific in eastern, southern and south western Australia, within 50-150 miles of the coast (Lamont 1973). It is also abundant in parts of northern Tasmania, the northern coastal lowlands, Hawkesbury Sandstone District in New South Wales and the coastal lowlands of Queensland. The climates in these areas can broadly be categorised as temperate with long, hot summers and mild winters. The soils, which are invariably sandy and deficient in most plant nutrients are some of the most infertile in Australia (Lamont 1973). Some of these floristically rich regions have predominantly winter rain such as West and Southern Australia (Burbidge

1960) but Johnson and Briggs (1974) point out strongly that these developments did not primarily depend upon the existence of Mediterranean (winter-wet, summer-dry) climates despite the fact that it has often been implied by many people in the past. Proteaceous genera are rich in the winter rainfall area of South Africa as well as Australia but it is more striking that they are adapted to a much wider variation in environmental factors (Lamont 1973). Floristically rich communities are found in areas like Eastern Australia under rainfall regimes ranging from summer maximum in Queensland, through even distribution in the Sydney district to winter maximum as the truly Mediterranean regions of South Australia are approached. It is particularly noteworthy that the "Mediterranean" parts of Australia, as noted by Specht (1969, 1972) do not support floristically rich vegetation where soil nutrient status is moderate or high. Successive evolutionary radiations appear to have taken place on deficient soils and under warm-temperate conditions of moderate rainfall but too dry for closed forest (Johnson and Briggs 1974).

Many habitats are exposed to strong prevailing winds while others may be more protected by landform or tree species. Proteaceous plants grow on the lowlands (sandplains) and also higher areas on laterite, limestone, granite or sandstone outcrops or flat planes and sand-dunes or steep valleys and cliff faces (Lamont 1973). Many of the Proteaceae have adapted to drought conditions and have become sclerophyllous with leathery or brittle leaves which have well developed cuticles and thick-walled cells (sclereids). These adaptations may also be due to poor nutrient supply (Beadle 1966, Specht 1972) although Johnson and Briggs (1974) point out that highly specialised "xeromorphic" anatomical features can hardly be a mere by-product of physiological adaptation; they are certainly genetically determined, though modifiable to some degree by internal environment of the developing organs.

Typical heathland vegetation consists of small stunted trees and shrubs, including Casuarinaceae (e.g. *Casuarina* spp.), Epacridaceae (*Epacris* spp.), Mimosaceae (*Acacia* spp.), Myrtaceae (*Eucalyptus* spp.) and Proteaceae (*Banksia* spp.) (Gardner 1959, Specht 1963). It invariably occurs on extremely impoverished acid to neutral sandy soils of the moist coastal areas of South West, South and Eastern Australia. The soils have very low available N, P, K and Ca, while Mo, S, Cu, Zn and B may also be extremely low (Specht, 1963; Stewart, 1959; Wood, 1959). P levels may be below 150 ppm in some soils of the S.W. Province of Western Australia (Beadle, 1962). Lamont (1973) pointed out that whilst the low levels of N, P and K occur in all areas and prevent the establishment of introduced horticultural plants, these soils are not always deficient in Mg, Ca, S, B , Co and Fe. He also noted that the soils are often acid, though they may be neutral, or even alkaline in the coastal limestone of the Perth Coastal Plain. The poorly drained sites are generally very acid.

Jeffrey (1967) considers that heathland Proteaceae have adapted to a low P and N requirement. Beadle (1954, 1968) also favours physiological adaptation and believes many of these plants have the ability to tolerate a low P turnover. Specht and Groves (1966) found that P is taken up in spring and stored as polyphosphate which is hydrolysed to orthophosphate and used in growth during summer. Wood (1959) showed that some species can pass into a static (but not dormant) condition when P and N levels are reduced, and remain in this state for up to two years. According to Wood (1959), the low fertility of the soils protects the heathland species against invasions by plants with a higher nutrient need.

Distribution and Habitat in South Africa

The Proteaceae is one of the most conspicuous flowering families of the flora in the South-Western region (winter rainfall) of South Africa due to the large number of species and their attractiveness (Werner 1951). Relatively few species are found in the summer-rainfall region. The origin (and other taxonomic features) of the African Proteaceae has been reviewed by Beard (1959) and Levyns (1964, 1970). Rao (1971) points out that the region is a secondary centre of diversification for the Proteeae tribe with all African taxa concentrated in the Cape Province.

The most significant feature, in common with the Australian Proteaceae, is that the majority of the South African Proteaceae are confined to mineral deficient soils, the most common example being those developed on the Table Mountain Sandstone (Johnson and Briggs 1974). Some species of *Leucospermum* extend into the summer rainfall region but always on siliceous formations (Rourke 1972) while others may occur in Eastern Rhodesia but still on deficient soils such as quartzites on old mountain formations (Wild 1968). Many of the Cape species are specialised mountain plants which have developed close adaptations to harsh local environments. The species of lower elevations show less adaptation but are more resilient than those that come from higher attitudes (Beard 1959). The latter, such as many proteas, are very intolerant of poor drainage and the still, humid conditions as found in glasshouses (Halliwell 1970). This is especially important for the summer rainfall proteas such as *Prctea caffra* (Vogts 1954). Proteas such as *P repens* and *P. scolymocephala* are from lower altitudes and are much more tolerant of fertile soils than are 'high altitude' species (Brits 1978, pers. comm). Other rapid-growing, 'robust', and widely distributed species are *Leucospermum candicans* and *Leucadendron adscendens* - these 2 genera are relatively easy to grow (Eliovson 1967). Some species such as *P. susannae* grow on limestone soils (Eliovson 1967) while other are seriously affected by alkaline conditions (Vogts 1954).

Proteoid Roots

Engler (1889) first noted the unusual root system on proteaceous plants and commented on the thick "absorption hairs". Purnell (1960) and Lamont (1972 b) gave detailed accounts of the morphology and anatomy of proteoid roots. Purnell (1960) defined a proteoid root as a dense cluster of rootlets of limited growth and occurring along a lateral root. They appear to last only one season and by the end of summer are dry and shrivelled although the parent roots last indefinitely (Purnell 1960, Lamont 1972 a). Lamont (1972 a) found them to be physiologically active for two to three months and they seem to be produced by the youngest roots of the root system. Proteoid roots may persist for up to a year on container grown plants where water is not limiting (Bradhurst 1954, Purnell 1960). Young proteoid roots are usually found on field plants in winter and spring while examination in summer usually reveals that they are dry and shrivelled (Purnell 1960). Proteoid roots begin to form on seedlings at the time the cotyledons are shed (Bradhurst 1954) and have also been noted by the author on cuttings at quite an early stage of development.

Proteoid roots have been found on a wide range of Australian Proteaceae (Purnell 1960, Jeffrey 1964 and 1967, Rao 1971, Lamont 1972 a and b, Pathmaranee 1974), and have been observed on South African genera by Hocking and Thomas (1974). They appear to occur on most Proteaceae and similar structures have been recorded on other plants such as *Viminaria juncea* of the family Papilionaceae (Lamont 1972 c) and members of the Cyperaceae (Davies *et al.* 1973).

Several studies have been made to determine the nutritional significance of proteoid roots. Jeffrey (1967) working in *Banksia ornata* heathland, found a discrete zone 2.0 - 3.5 cm thick in the soil profile composed of a mass of proteoid roots. The zone was not more than 5 cm deep and proteoid roots penetrated from it into the litter layer. Under some conditions the proteoid root carpet may be almost continuous. Jeffrey (1967) considers it may act as a trapping surface for nutrients from a number of sources including cyclic salts and litter decomposition. In glasshouse culture they have been observed to develop on the top surface of a moist bench.

The development of proteoid roots is greatly influenced by nutritional and environmental factors but Pathmaranee (1974) concluded from a detailed research study of their biology that 'research on the functioning and influence of proteoid roots is clearly in its infancy'. Earlier authors agreed that they functioned in the absorption of nutrients, particularly phosphorus (Purnell 1960, Groves 1964, Jeffrey 1967). Jeffrey (1967) found that they were very effective at absorbing P and considered that this was due to their large surface area. Proteoid roots appear to grow more prolificly where there is high rather than low levels of soil organic matter (Purnell 1960, Lamont 1973, Pathmaranee 1974). The work by Lamont (1972 b) on the proteoid root production by *Hakea* species demonstrates the complexity of factors governing their development. He showed that the proportion of proteoid roots can vary in 4 phases as nutrient availability increases. In the field there are 2 important stages, starting with an increase in proteoid root production as non-proteoid root growth increases, which is followed with a decrease in proteoid root production as non-proteoid root growth increases. He concluded that nutrient concentration, especially nitrogen availability, largely determines the relative contribution of proteoid roots to the root systems of *Hakea* species. Total N, available nitrate, P, Ca, and Mg suppressed proteoid root production while increased pH and bulk density occasionally promoted their production. Interactions also occurred, particularly between N and P. The characteristics of the *Hakea* root system varied since very few laterals grew at low N and high P but when added N and P were both high there was a far larger proportion of fine laterals than at low levels of these two nutrients.

The Proteaceae do not appear to be mycorrhizal (Purnell 1960) although Pathmaranee (1974) felt that it is not possible to conclude that the family as a whole is not mycorrhizal. She showed that *Telopea speciosissima* grown in axenic culture produced proteoid roots, which indicates that proteoid roots do not arise as a result of an invasion by an endophyte. In contrast Lamont and McComb (1974) found that proteoid roots developed in sterile soil and they concluded that their formation was stimulated by soil micro-organisms but which themselves did not invade the parent root. Pathmaranee (1974) drew attention to several parallels between the function and occurrence of proteoid roots and mycorrhizas. They both assist plants to grow on low nutrient status soils (particularly deficiency P), their occurrence is depressed when the nutrient status of the soil is increased (Baylis 1967, Harley 1969, Mosse 1973), plants are not obligately dependent on them and both may be more abundant in humus - rich surface soil horizons than deeper zones (Harley 1940, Mikola *et al.* 1966). Baylis (1972) commented on the evolution of root systems and stated that root hairs and mycorrhizas may have developed as alternative methods for obtaining phosphorus.

Nutrition of the Proteoideae

Some general comments on the cultivation of South African proteaceous plants have been made by South African and other horticulturists. Werner (1951) recommended that these plants should be potted-up into an average light soil enriched with some compost or leaf mould with a little bonemeal added. He recommended adding a little bonemeal and/or a dusting of super-phosphate at planting. Vogts (1954) warned against the use of manure while Stevens (1965) in Wanganui, New Zealand recommended the opposite and stated that he used tons of year-old animal manure in his garden with no ill-effects on proteas etc although he never used artificial fertilisers. Manure dug deeply before planting may, however, have serious consequences with proteas (Vogts 1954).

Parvin *et al*. (1973) discussed the culture of proteas and similar genera, and stated that knowledge of the native environment of proteaceous plants has provided little guidance to their nutrition. They went on to say that recommendations varied from no fertilisation (Eliovson 1968) to a "standard" fertiliser program (Watson and Parvin 1970). This statement by Parvin *et al*. (1973) appears to indicate a lack of understanding of the requirements of these plants and the reports on their native habitats. Thomas (1974) was one of the first workers to make a detailed study of the nutrition of container grown plants and it appeared that the native environment of the plants was strongly related to their nutritional response under nursery conditions.

Parvin *et al*. (1973) observed nutritional disorders in several species of *Protea* and noted that new leaves were often red but developed marginal necrosis and eventual distortion. They noted that calcium levels were consistenty low in unhealthy plants and that P was also often very low compared to those obtained in *Macadamia* (Cooil *et al*. 1966). This latter comparison needs to be done very guardedly however, since *Macadamia* is in a different sub-family to *Protea* and more important evolved in a very different habitat in another country.

The effect of mineral deficiencies on the growth of proteas has been reported by van Staden (1967, 1968 a, b). He grew 2 species of protea in sand culture and found the plants were very sensitive to variations in trace element supply and some macro nutrients. In *Protea cynaroides* the dry weight of leaves and stem length were reduced by low levels of K, Ca and occasionally N, while a lack of P, Mg, S and Fe had no significant effect on any of the characters measured. However soil deficiencies of N, K, Ca and Fe reduced the Fe content of the plants and resulted in severe chlorosis and necrosis of the foliage.

Nutrition of the Grevilleoideae

Beadle (1966) considered that members of the Australian flora adapted to low fertility conditions show accentuated xeromorphic characters through a reduction in leaf size. *Banksia*, *Hakea* and others were grown in containers with soil from their native sites. There was a strong and positive growth response to added nutrients (Hoagland's solution) with several showing changes in leaf morphology and an increase in foliar P content correlated with P levels in the medium. Superphosphate and sodium nitrate strongly increased the growth of Australian heathland plants on impoverished sandy soils but there was greatly increased mortality of seedlings and P toxicity was observed as yellowing of the foliage on plants like *Banksia* (Specht 1963). Heddle and Specht (1975) later concluded that added P increased the growth of well established 'adult' plants and tended to speed up their life cycle, causing them to die many years earlier than usual. Phosphorus was retained in the ecosystem for 2 decades at least and caused the death of almost all seedling heath plants including 2 species of *Banksia*. Grundon (1972) made similar observations when applying fertiliser to Queensland heath plants. He found that those in the Proteaceae (*Banksia* and *Hakea* spp.) showed the greatest capacity to utilise low levels of P and that varying responses of heath species, particularly those of the Proteaceae, to high levels of P depend not on varying sensitivity of tissues to high P content, but rather on the amount of P taken up by the plants in media with a extreme imbalance in the P:N or P:K ratio, such as with high P and low N or K. These heath plants were unable to avoid excessive 'luxury consumption' of phosphorus, leading to toxicity. Many of the damaged plants had foliar P levels of more than 1% compared to 0.03 - 0.07 at the lowest level of added P. These effects were more severe at low N and in the case of *Banksia* spp. at low K levels.

Hodge (1970) reported that fertilisers high in phosphate have been responsible for the death of many grevilleas. Iron chelates and sulphate of ammonia were recommended to correct chlorosis. Higgs (1970) in nursery container trials found that *Grevillea rosmarinifolia* developed chlorotic foliage with full strength fertiliser treatments at normal depths of planting. He found that as time passed, growth was inhibited and the lack of vigour became noticeable compared with the healthy appearance of plants grown in the half strength and nil fertiliser treatments. Moore (1966), and Moore and Keraitus (1966) grew *Grevillea robusta* in perlite using nutrient solutions and found that development of deficiency symptoms for N and K depended both on the absolute level of each nutrient and also the balance of the two. This was particularly evident for K deficiency. There was a strong N growth response especially at high K while yellowing occurred at low N and necrotic spots at low K.

Jeffrey (1964) has shown that many Proteaceae are calcifuges, and because they are adapted to make maximum growth at low Ca levels, they are unable to avoid excessive and toxic Ca uptake when grown in soils with high levels of Ca. Hockings (1970) states that, in general, grevilleas prefer a soil with definite acid reaction but that there are two quite well known exceptions, namely *Grevillea robusta* and *G. striata*, both of which can thrive in alkaline soils. Lamont (1973) states that iron chelates may be necessary to combat chlorosis on proteaceous plants in calcareous soils. Liming is, however, recommended for some species and a range of species have been observed to flourish in limestone areas (Lindross 1977). In general, fertilisers and lime should be applied with care especially materials, such as Magamp, which have a high N and P content (Hockings 1970). Lamont (1973) suggested that manure or artificial fertilisers for species of the Proteaceae should only be applied at one tenth of the rate recommended for other species.

Nutrition of Other Australian Plants

It has been established that Australian proteaceous plants inhabit the most infertile sites and are therefore intolerant of high fertiliser regimes, particularly high P. Other genera such as those in the Myrtaceae and Mimosaceae are faster growing but are less able (than the Proteaceae) to grow in very infertile soils (Lamont 1973). Grundon (1972) established the controlling effect of soil fertility on the delineation of plant communities by showing that the Proteaceae had faster growth rates than other heath or introduced species only in very infertile conditions and that this advantage was soon lost if the nutrition plane was raised.

Acacia

This is a large tropical to temperate inhabiting genus of the Mimosaceae and the majority of the approximately 1,000 species occur in Australia (Hopper and Maslin 1978). Pettigrew and Watson (1975) reassessed the classification of the genus *Acacia* and noted that the endemic Australian species form a coherent taxonomic group within the genus as a whole. They divided the Australian species into two main series of Heterophyllum (e.g. *A. drummondii*) and Uninervea (e.g. *A. verticillata*) with the latter primarily for the uninerved phyllodinous species.

Some species have become highly adapted to extreme soil conditions. Thus *A. harpophylla* can tolerate salinities up to and beyond sea water concentration and was found to have special mechanisms for conservation of its water supply (Gates 1972). Others such as *A. obtusata* may be highly adapted to live in very infertile soils (like many Proteaceae) and were found to be extremely intolerant of high P levels in the medium (Frolich *et al.* 1966). *A. obtusata* plants watered with 0.001 and 0.002 M P solutions contained nearly 1.9% P in the foliage compared to 0.5% for those watered with 0.0003 M solutions. Fairall (1970) states that nitrogenous fertilisers should be used very sparingly, if at all, as they produce an overgrowth of foliage at the expense of flowers.

Boronia

Boronias belong in the Rutaceae which is a widely distributed family, numbering approximately 150 genera from hot and temperate regions of the world. Boronia is in the tribe Boronieae of which 18 are from Australia and are widely distrubuted (Armstrong 1975). Some species such as *Boronia heterophylla* and *B. megastigma* can survive under harsh conditions and tolerate very alkaline soils (Alcock 1976, Lindross 1977). Fairall (1970) however states that they generally react poorly to alkaline conditions. Hewett (1975) reported that many boronias are very difficult to grow in Australian gardens and mentioned nematodes, *Phytophthra* and *Pythium* as common problems. He recommended a low feeding rate of red Nitrophoska for open ground plants. Harrison (1960) states that they are all peat loving, but thrive in any lime-free soil that is well drained and never allowed to get very dry. Many grow on raised hillocks or decayed tussock in their native habitat, and usually in swampy ground (Harrison, 1960). They are often found to be comparatively short-lived in gardens (Alcock 1976).

Callistemon

Prakash (1969) looked at various aspects of the life history of *Callistemon citrinus* and noted that the genus contains 25 species which are native to Australia and New Caledonia. This genus belongs in the Myrtaceae (along with *Eucalyptus*) and is reported to be able to withstand hot, dry and poor soil conditions (Harrison 1960). Fairall (1970) states that they react well to small amounts of organic fertilisers applied in autumn.

Eucalyptus

Moore and Keraitis (1971) grew plants of 12 eucalypt species in sand culture and found that there were wide variations in the preferred form of N and that their responses could be grouped according to their ecological situations. Woodland species responded with maximum growth when NH_4-N did not exceed half the total soil N while others responded to ammonium even when the only nitrogen source. Eucalypts can grow in fairly impoverished soils but can also produce rapid growth in more fertile soils (Pryor 1975). Over-stimulation with fertilisers will, however, encourage rapid, lush growth which is easily damaged by weather extremes and therefore young plants should not be fed till well established in their second or third growing season (Fairall 1970).

Attiwill (1964) found that seedlings show a marked ability to survive with a very low P supply which is mediated by their ability to redistribute it within the plant. Potted plants responded strongly to added P but only to modest additions. Mycorrhizas were also shown to play an important role in P uptake by eucalypts (Malajczuk *et al.* 1975).

Kaul *et al.* (1966 a, b, 1968, 1970 a, b) carried out a series of experiments on 3 species and groups of hybrid eucalypt seedlings to evaluate the effect of removing N, P or K from the growing medium. In all cases a lack of P caused severe deficiency symptoms of stunted growth and chlorosis and/or necrosis. *Eucalyptus citriodora* also showed severe deficiency symptoms in the absence of K. *E. globulus* was severely effected by a lack of N or P and less badly influenced by no K in the medium. This species when sidedressed at 15 months with N and P responded very strongly compared to unfertilised plants in the open ground (Cromer *et al.* 1975). *E. grandis* also grew very strongly with added N and P after planting-out (McIntyre and Pryor 1974).

Pryor (1975) states that the great sensitivity of eucalypts to soil nutritional status is related to their nutrient cycling and nutrient balance in natural stands and that N and P additions have often been particularly important for the early growth of eucalypt plantings in various parts of the world. He also pointed out that they are extremely tolerant of low levels of many of the minor elements.

Several workers have indicated the importance of genotype and habitat on nutritional requirements. Lidges (1974) found that *E. viminalis* did not respond strongly to various rates of 'complete' liquid feed applied to potted seedlings grown in sand. Populations derived from the most fertile areas grew the most rapidly. Similarly Parsons and Specht (1967) found in pot experiments that certain species demonstrated that particular ecological groups can become highly tolerant of calcareous media while other species can show severe stunting and chlorosis under similar conditions (Parsons and Specht 1967). Moore (1961) also did pot experiments and found that certain species were very responsive to exchangeable calcium levels. Recent work by Anderson and Lidges (1978) demonstrated that chlorosis was associated with the inability of species to assimilate P, K, Mg, Ca and Na. They concluded that plant species from acidic soils (calcifuges) can have quite different mineral nutrition to those from calcareous soils (calcicoles). These differences can be quite large even within the one genus of *Eucalyptus* or between different populations of species.

Nutrition of Northern Hemisphere Shurbs

Camellia

Furuta (1969) classified plants into 3 groups according to their sensitivity to soluble salts. Camellias were placed in the most sensitive group and were considered intolerant of moderate salinity levels. Excess fertiliser is one of the most common sources of injury to camellias in horticulture and the main requirement for growth is plenty of organic matter and water plus good drainage (Pearson 1958, Wills 1971).

Nitrogen is considered the most important major element for camellia growth (Bonner and Honda 1950, Furuta *et al.* 1954, North and Wallace 1966, Bates 1971). Bonner and Honda (1950) reported that P and S were less critical while K, Mg and Ca favoured vegetative growth. Increasing K levels resulted in reduced growth. Furuta *et al.* (1954), using peat/sand

(1:1) for container culture, concluded that an NPK ratio of 3:2:3 produced the most vegetative growth.

Bonner (1947) found that increasing fertility from a low to medium plane of nutrition greatly increased flower bud set when combined with high light intensity. Scott (1977) reported on trials carried out on *Camellia* flowering over several years. High N combined with adequate P and K were found important for bud set. The results varied with the variety and season.

Camellias are considered to prefer a higher than normal proportion of ammonium to nitrate in their nutrient supply (North and Wallace, 1966). This is supported by research on tea (*C. sinensis*) by Ishigaki (1974 and 1975), Ishigaki and Hoshina, (1977) and Selvendran and Selvendran (1973). The latter found that the N content of the foliage increased steadily for about 40 days following N fertiliser application. Ishigaki and Hoshina (1977) found tea plants sensitive to high levels of all macro nutrients and that NH_4-N gave increased growth coupled with higher uptake of N, Mn, Al and Fe than with NO_3-N. Some nutrient antagonisms occurred including K:NH_4-N and Mg:K using sand culture experiments.

Willson and his colleagues reported on a series of experiments in Kenya which examined the response of tea (*Camellia sinensis*) to N, K, Ca, Mg (Willson 1975 a, b, c, d) and P fertilisation (Willson *et al.* 1975). Nitrogen additions gave the greatest growth response and tended to reduce the foliar levels of base cations. The response to other fertilisers was generally minor despite the fact that potassium was found in greater amounts than the other macro-nutrients measured in the foliage.

Choisya

This shrub is in the Rutaceae and is native to Mexico. It was reported as being adaptable to a wide range of conditions (Harrison, 1960) and is commonly grown in New Zealand gardens, particularly Canterbury because of its tolerance of cool wet winters and warm dry extremes of summer.

Erica

Plants in the Ericaceae (and Theaceae) are very susceptible to salt damage (Klougart and Bragge Olsen 1969). Ericas require only low concentrations of liquid feeds (50 ppm of N and K_2O) compared with up to 200 ppm for other plants (Carter 1973). Morgan (1973) grew *Erica carnea* 'Springwood White' with a range of slow release fertilisers and found Osmocote was the most suitable since chlorosis occurred with others like Enmag and Planosan, even though the plants had grown well. The same cultivar appeared more prone to poor establishment after potting, chlorosis and die back if grown in soilless media rather than in a John Innes mix, especially when high feed rates were used (Anon 1971).

John Innes composts were found to be unsuitable for calcifuge plants. *Erica* species were used to investigate the use of 'flowers of sulphur' as a substitute for chalk in the composts (Sutton 1958) and appeared to prefer an acid medium. Susceptibility to chlorosis was observed to vary according to the species, and it was found that the trouble was least likely to occur at pH's below 6 and prevented by maintaining the pH at between 4.5 and 6.0 (Alvey 1955). It was also noted that there was less chlorosis in loamless rather than soil media but growth was better in John Innes potting mixes. Gray (1971) gave recommendations for treatment of soil mixes to make them lighter and improve their aeration. Improving the physical characteristics of media such as increasing the aeration would help overcome chlorosis problems reported by early workers.

Objectives of Study

The objectives of this study were to examine the comparative nutrition of a range of container grown species with emphasis on the Proteaceae. Work initially concentrated on serious problems encountered by New Zealand nurserymen in container culture of proteaceous shrubs. Further work indicated that it would be of value to look at the comparative nutrition of an increasing range of plants particularly since difficulties were being encountered with other species. It was convenient to widen the scope of the work because the investigating techniques had been broadly standardised. In other words media, fertilisers and growing conditions could remain relatively constant while different plants could be 'screened' for their nutritional needs to allow emphasis on comparative nutrition which became the main objective of the work. In this way such inputs as media, fertilisers and growing conditions were held relatively constant in order to emphasise the nutritional characteristics of different nursery plants. This was reinforced by repeating experiments so that the influence of variables such as time of year and its consequent effect on growth via photoperiod etc could be minimised.

The standardised techniques used had the secondary objective of providing information which could be directly related to nursery container production. This appeared important not only to overcome difficulties in the culture of plants like proteas but to aid in the design of media which will improve the efficiency of production techniques. Research carried out with this objective has been very limited particularly with Southern Hemisphere shrubs since much of it has primarily been done to study ecological and botanical features. This work therefore utilised media, fertilisers and growing techniques which were as closely related as possible to commercial practise. Osmocote slow release fertiliser and the commonly used peat/perlite and peat/sand media were therefore chosen.

Many nurserymen attempt to grow a wide range plants species in the same general potting mix. The most profitable approach is to produce plants as rapidly as possible to the maximum size, in the shortest length of time and with minimum losses. This work is potentially of most benefit to the large scale or specialist producer who is able to modify media nutrient levels to suit the specific requirements of groups of similar species.

To meet the objectives of this study the work began with a basic examination of the nutrition of *Grevillea rosmarinifolia* including soil and foliar analyses (Chapter 1). This species became the main test plant and was used in 8 of the 35 experiments (Appendix I). Chapter 2 reports on the comparative nutrition of 4 widely differing species which were all grown in similar 2^3 factorial experiments. The significance of soil *v* soilless media and types of fertiliser was then studied (Chapter 4), using tomato as a high fertility plant in contrast with two proteaceous shrubs. Three Australian and 1 Mexican shrub were then investigated in Chapter 5; these were from 3 families other than the Proteaceae. In Chapter 6 the detailed nutrition of 2 proteaceous shrubs and 1 Australian species, involving nutrient response surfaces, was studied. This was then followed by a similar examination of the nutrition of an erica species and then the comparative nutrition of a range of pot plants and seedlings. Finally Chapters 9 and 10 concentrate on the N and P nutrition of a wide range of species.

CHAPTER 2

NUTRITION OF CONTAINER GROWN

GREVILLEA ROSMARINIFOLIA A. CUNN.

ABSTRACT

Nutrition of *Grevillea rosmarinifolia* was studied in two experiments. Plants were grown in 'Plantabags' with peat/perlite (1:1, vv) supplied with slow release and conventional nursery fertilisers. Plants responded strongly to 450g N/m^3 but were severely depressed if 300g P/m^3 was also added. High foliar nutrient levels occurred if N and P fertilisation was high, while proteoid root production was strongly suppressed under these conditions.

INTRODUCTION

The container culture of proteaceous shrubs in New Zealand has often presented difficulties because nurserymen have often failed to fully appreciate the nutritional requirements of these plants. This has lead to toxicity from excessive levels of N and P, while others may grow these plants with inadequate nutrient supply in order to avoid fertiliser damage.

Grevillea rosmarinifolia is a typical cultivated species from the Australian heathlands. The soil of these regions are generally very infertile being low in N, P, K, Ca and trace elements (Specht 1963; Stewart 1959; Wood 1959). Beadle (1954, 1968) and others have stated that these plants are adapted to growing under a low N and P regime and some species can store phosphate until it is required in the growing season (Specht and Groves, 1966). Most Proteaceae have proteoid roots (Pathmaranee 1974) which are primarily an adaptation to low fertility conditions (Lamont 1972 b). Their presence has sometimes been noted by nurserymen and information on the significance of these root structures in terms of occurrence and relative importance in nursery media appears to be needed.

The two experiments reported here were designed to examine the response of container grown *Grevillea rosmarinifolia* to various levels of fertilisers. They also provide basic information for further studies on the comparative nutrition of a range of nursery proteaceous species and other non-related groups.

MATERIALS AND METHODS

Plant Species and Growing Conditions

Grevillea rosmarinifolia was grown in two experiments involving 400 plants as shown below:

	No. of Treatments	Replicates (Plants/treat.)	Dates Bagged	Dates Lifted
Expt. A	13	24	22.9.72	2.5.73
Expt. B	8	10	14.12.73	6.8.74

All plants were raised in a glasshouse from semi-ripe tip cuttings under mist and were potted-up into tubes containing very low nutrient levels. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Hand watering was done when required and no fertiliser side-dressings were applied.

Experimental Design, Media and Fertilisers

The experiments were both 2^3 N, P, K factorial designs using randomised blocks. Five additional treatments were added to Experiment A (Table 1). The medium used was equal parts (1:1, vv) Southland sphagnum peat (Dipton) and fine grade perlite. The physical and chemical characteristics of each medium were described by Goh and Haynes (1977 a) and Morrison *et al.* (1960), respectively. A base dressing of 0.25 kg of Osmocote 18/2.6/10 was used for all treatments. Additional rates of N, P and K were supplied from Osmocote (26% N), Superphosphate (9% P) and sulphate of potash (39% K) respectively. All treatments received a basal dressing of the following: 4.5 kg/m^3 dolomite lime, 1.5 kg/m^3 agricultural lime ($CaCO_3$), 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB5 (2½l) 'Plantabags' just prior to potting.

Media Analysis

A range of soil analyses were carried out on potting media from Experiment A, 2 months (23.11.72) after potting. Three samples of 3 cm diameter to a depth of 8 cm were obtained from pots in specific treatments aggregated together and mixed to give a composite sample. Nitrogen analysis was carried out in the Lincoln College Soil Science laboratory using the Kjeldahl N digestion technique. Hoskins steam distillation with magnesium oxide for determining exchangeable ammonium and titanous sulphate for nitrate were used.

Soil analyses were carried out by Vautier Enterprises Ltd (now Water, Soil and Laboratory Services, Napier) who used Truog extraction for P, K, Ca and Mg and soluble salts by the methods described by Metson (1956).

Foliar Analysis

Five samples of foliage were randomly selected from plants in factorial treatments in Experiment A. These samples were then sent to the Ministry of Agriculture and Fisheries at Ruakura Research Station where samples were ground and then analysed to determine the levels of N, P, K, Mg, Ca and Na.

Nitrogen levels were determined using the sodium phenate method which was adapted from the Gehrke-Wall method for automated nitrogen methods for feeds (Gehrke, Wall and Absheer, 1973). Gehrke, Wall and Absheer found their method compared well with Kjeldahl analysis. Phosphate was determined using the molybdenum blue method in the perchloric acid system described by Jackson (1958) and modified for use with an auto analyser. Potassium, Ca and Na were determined using flame photometry as described by Allan (1958) and Mg analysis was by atomic absorption (Allan 1959).

Data Collection and Analysis

Visual ratings of foliage vigour were carried out on 13.11.72, 12.12.72 and 30.4.73 for Experiment A and 15.5.74 for Experiment B using the following grading system:-

0 = plant dead

1 = very poor

2 = fair, lacking vigour, sub-standard

3 = average grade

4 = vigorous

5 = very vigorous, strong and high quality

This type of rating has been used for nutrition studies by Dickey (1967) and Dickey *et al.* (1961) and other workers. On completion of each experiment the plants were cut off just above the top of the medium and the foliage oven-dried. The root system of plants in the factorial part of Experiment A were examined and the proteoid roots were assessed by counting the number per plant which were greater than 1 cm long.

Foliar analyses, proteoid root numbers, visual ratings and dry weights were statistically examined using Teddybear (now Crypto/teddybear) computer programme for analysis of variance and F test.

RESULTS AND DISCUSSION

Growth Response

Visual ratings of the foliage of plants in Experiment A after 2 months indicated N and P toxicity (Table 1)[+]. Ratings after 7 months for Experiment A and at 4 months for Experiment B then showed a positive response to N which was strongly substantiated by the dry weight yields. A strong negative NP interaction was apparent in all data in the first visual rating for Experiment A. High P rates totally suppressed the positive response to N and there was severe toxicity when both elements were combined at high levels (Table 2). There was generally a strong positive response to N in the absence of high P and alternatively high P was not quite as toxic when accompanied by low N. Several 3 factor interactions occurred in Experiment A and in this experiment the unfavourable combination of N and P, was made worse at high K. Specht (1963) stated that Australian heathland species should not receive inorganic fertilisers. Lamont (1973) also advised that favourable growth of proteaceous species requires low nutrient levels, however it appears that *G. rosmarinifolia* can be grown with inorganic materials and that N should be added but only at moderate levels. No chlorosis was observed despite the fact that Higgs (1970) noted it with this species grown in a U.C. type mix based on peat and sand.

The results in Experiment B generally supported those of the first trial and medium N plus low P and possibly low K can be recommended for the growth of container grown *G. rosmarinifolia.* The additional treatment with very high NPK levels was clearly highly toxic (Table 1) and this species appeared to barely tolerate the very low nutrient levels of the nil fertiliser treatment. The results did indicate however, that plants with nil fertiliser were in excellent condition at 2 and 3 months and could be held for short to medium terms at low nutrient levels. This was also

\+ *Refer to insert booklet for Experimental Tables.*

found by Higgs (1970) who noted that *G. rosmarinifolia* did better with nil or half-stength fertiliser than at higher rates, in a short-term experiment.

Proteoid root numbers per plant in Experiment A were heavily reduced by high levels of N, as indicated by the main effect of this nutrient (Table 3). Increased P also retarded their growth, particularly in the presence of high N or K fertilisation (Table 4). The effect of high K additions was unpredictable since they mildly stimulated proteoid root numbers at N_0 P_0 but at N_1 P_1 assisted in the virtual suppression of all proteoid root production. No proteoid roots at all were found in Experiment A in the additional treatments receiving very high NPK levels. The additional treatment with nil NPK had a mean number of 44.0 per plant. This surprisingly low figure relative to that with small additions of N and P may indicate that low nutrient levels have a mild stimulating influence on proteoid root formation although media N, P, K levels in these treatments were not found to be greatly different in the unfertilised pots when sampled (Table 7). These results are in agreement with Pathmaranee (1974) (also Lamont (1972a)who found that the greatest proportion of proteoid roots occurred at added but low P and N levels and that increasing these nutrients strongly suppressed their occurrence in 2 proteaceous species.

Foliar analyses (Experiment A.)

Foliar N levels were greatest in the presence of high P and K fertilisation (Table 5) and were also high where these nutrients were maintained together at low levels in the medium (Table 6). Foliar levels of P and K were strongly depressed and Ca moderately reduced by 450g N/m^3. Foliar Mg was reduced most strongly by high N additions combined with low P fertilisation while the opposite occurred with Na uptake since this was most strongly promoted at N_1 P_1.

Added P promoted the uptake of N, P, K and Na, and there was no significant depression of any of the 6 foliar nutrients. High K fertilisation increased foliar P and K levels. Uptake of Mg was mildly depressed by 250g K/m^3 if added P was at low levels.

It was notable that foliar N levels with N_1 P_1 K_1 were nearly 2.5 times greater than with N_0 P_0 K_0 and that high P fertilisation doubled the levels of foliar P and increased the uptake of N, K and Na. Accumulation of high levels of nutrients in the foliage would account for the toxicity effect and growth depression which occurred when N and P are added at high levels to the medium. This is supported by the fact that P toxicity symptoms usually appear as distortion, stunting and necrosis of the foliage. Loneragan *et al.* (1966) considered that P concentrations in excess of 0.8% of dry weight of shoots could cause P toxicity symptoms in plants. Generally foliar P levels reported here did not reach that level but responses varied with species and other fertilisers.

Grundon (1972) grew *Banksia* and *Hakea* spp. in nutrient solutions using a simple non factorial experiment and observed P toxicity but concluded that it occurred much worse at low N levels rather than high levels as reported here. He pointed out that differences between sensitive proteaceous species and others like tomato to high P was not due to sensitivity of tissues to high P content, but rather on the amount of P taken up by the plants under conditions of extreme imbalance in the N:P or K:P ratio.

The work reported here (and subsequent experiments) indicate that Grundon's conclusions do not appear valid for container grown plants and P toxicity is most likely to occur when N and P are both high rather than when imbalance occurs between these 2 nutrients.

Media Analyses

Table 7 gives the levels of ammonium and nitrate nitrogen found in the media in the factorial and additional treatments after 2 months. The 45g N/m^3 supplied as a base dressing (from Osmocote) in all but the nil treatments yielded only a small amount of N which was only about double the additional treatment containing no NPK additions. Generally the total amounts of N found, correlated well with the fertiliser N supplied and the 450g N/m^3 treatments contained about 10 times the levels of NH_4 and NO_3-N as the low rate (Treatments 1-4). The proportion of the two N forms was relatively even except for the predominance of NH_4-N in the 2 additional treatments containing the very high fertiliser N rate. These results are to be expected since NH_4 and NO_3-N are normally released in approximately equal amounts from Osmocote fertilisers (Bunt 1976), for example this formulation of 8-9 months Osmocote contained 53% of the N as NH_4 and 47% as NO_3.

Phosphate levels (Table 8) were often close to the total gP supplied while the nil fertiliser treatment appeared to contain almost as much P as those with 30g P/m^3. This is partly explained by the fact that 6.5g P of the 30 supplied was from 8-9 month Osmocote and that Osmocote is generally a slow and relatively poor source of P (Cochrane and Matkin 1967). Levels of potassium found in the media were relatively proportional to amounts supplied and Mg and Ca in plentiful and fairly uniform amounts although very high P levels appeared to increase the total Ca in the medium.

Soluble salt levels were moderately increased by high levels of the 3 added nutrients. Added fertilisers initially increased the acidity but after 7 months pH's were quite uniform with an overall mean of 5.2. Media samples were also sent to the Invermay Agricultural Research Station where the standard 'Quick Test Methods' were used. These analyses confirmed the ones done by Vautier.

CONCLUSIONS

Duplicate experiments with *Grevillea rosmarinifolia* primarily supported each other and indicated that this method of assessing the NPK response of container grown nursery plants is sufficiently reliable. Most work on the nutrition of container grown shrubs has involved complete fertilisers usually in simple design experiments whereas the experiments reported here primarily involved single nutrient fertilisers (e.g. Osmocote 26% N) in order to utilise factorial combinations of N, P and K. The method used therefore combined the advantages of applying individual nutrients, as in hydroponic type experiments, while still making use of the type of fertilisers and growing system used by commercial nurserymen.

This species originated in infertile soils in Australia but will grow strongly in response to quite high N fertilisation. The commercial implications are that a moderate level of complete fertiliser (if low P analysis) should be used in order to supply about 90g N/m^3 per month (Thomas 1974). Proteoid root numbers will be depressed by these levels, however rapid growth and economic production can occur without their presence.

CHAPTER 3

NUTRITION OF CONTAINER GROWN GREVILLEA ROBUSTA (L.) L., PROTEA REPENS L., CAMELLIA JAPONICA L. AND LYCOPERSICON ESCULENTUM MILL. 'BEST OF ALL' (TOMATO).

ABSTRACT

The nutrition of 3 woody plants and tomatoes was compared using plants grown under glass, in containers with peat/perlite (1:1, vv) supplied with Osmocote 26% N, superphosphate and sulphate of potash for the supply of N, P and K. *Grevillea robusta* responded strongly to N and proved to be tolerant of high P levels.

Protea repens responded differently to *G. robusta* and was initially injured by high N levels and killed in all cases where 300g P/m^3 was supplied. High P additions, especially when accompanied by high N, caused luxury and toxic accumulation of nutrients in the foliage. Foliar P levels were increased by 9X and N, K, Mg, Ca and Na uptake doubled by a high P supply.

Camellia japonica was initially intolerant of high N fertilisation and showed negative NP and NK interactions. High N levels were antagonistic to K, Mg and Ca uptake and camellia was very tolerant of a low nutrient supply.

Tomato contrasted strongly with camellia and protea, and growth was strongly promoted by high N especially at high K. It was very intolerant of low nutrient levels and growth was influenced by a negative NP interaction. High K additions were generally antagonistic to uptake of other nutrients.

INTRODUCTION

Experiments described in the previous chapter examined the NPK nutrition of *Grevillea rosmarinifolia*. Work on a further two proteaceous shrubs and 2 unrelated species is reported here. *G. robusta* is obviously closely related to *G. rosmarinifolia* but is derived from a different habitat. *G. rosmarinifolia* comes from the impoverished Australian Heathlands while *G. robusta* is native to Queensland rainforests.

Hockings (1970) stated that *G. robusta* is an unusual species since it prefers more alkaline conditions than most others in the genus. It has been found to respond to increasing levels of nitrogen especially when combined with high potassium (Moore 1966, Moore and Keraitis 1966).

Protea repens is also in the Proteaceae but in the sub-family Proteoideae rather than Grevilleoideae. In addition proteas are native to South Africa and because of the infertile soils of their native habitat are very sensitive to any form of fertilisation (Vogts 1954). Van Staden (1967) and Parvin *et al.* (1973) have observed and described deficiency symptoms in proteas. Watson and Parvin (1970) stated that premature death of proteas is common at any age but mostly attributed this to watering problems. They point out that observations indicate that proteas respond to standard fertiliser programmes. Serious problems with the container culture of proteas have been observed in New Zealand nurseries (G. Smith, pers. comm.).

Camellia japonica and tomato experiments are also reported here in order to compare the nutrition of proteaceous plants with others as done by Specht (1963). He compared the effect of fertilisers on various herbaceous species and on South Australian heath species including several in the Proteaceae. Several workers have looked at the feeding of camellias including Bonner and Honda (1950), Furuta (1954), North and Wallace (1966), Ishagaki (1974 and 1975) and others. Many have also studied the feeding of container grown tomatoes including Bunt (1969) and Woods *et al.* (1969). The former worker found that the response of tomato seedlings to N and P varied according to the season.

MATERIALS AND METHODS

Plant Species and Growing Conditions

Four experiments involving 700 plants were carried out and the species involved and laying-down details were as follows:-

Expt.	Plant Species	No. of Treatments	Replicates (Plts./treat.)	Dates Bagged	Dates Lifted
A	*Grevillea robusta*	8	10	14.12.73	6.8.74
B	*Protea repens*	8	15	26.3.73	10.6.74
C	*Camellia japonica*	8 + 5	25	25.9.72	25.9.73
D	*Lycopersicon esculentum* 'Best of All' (tomato)	8 + 5	15	14.6.73	25.8.73

Plants were raised from seed and pricked out into tubes containing very low nutrient levels except for tomato which was transplanted directly into the final containers. All experiments were carried out in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15°C while the maximum was close to 5°C above ambient temperature. Hand watering was carried-out as required.

Experimental Design, Media and Fertilisers

All experiments were based on a 2^3 NPK factorial with 5 additional treatments for Experiments C and D. The same rates as those given for Experiment A in Chapter 1 (plus one treatment with slow release Osmocote) were used and are given in Table 3. The same visual ratings were used as those described in Chapter 1 for Experiment A (Table 1). The medium for all experiments was equal parts (1:1, vv) Southland sphagnum peat (Dipton) and fine grade perlite as described for Experiment A, Chapter 1. All fertiliser details, foliage analysis and data collection was the same as before.

RESULTS AND DISCUSSION

Grevillea robusta

This species responded very strongly to nitrogen while no other main effects nor interactions were significant (Table 1). It was noteworthy that equal growth occurred at high P as at low levels with absolutely no indication of toxicity. Foliar levels at harvest are shown in Table 4 where again there were no interactions. High N fertilisation only mildly increased foliar N (P = 0.08) while uptake of K and Ca was strongly depressed. Increased P levels in the medium promoted foliar levels of all elements except K, with P and Ca uptake being particularly strong. High levels of added K strongly enhanced foliar K and mildly increased P uptake.

Grevillea robusta is native to Queensland and its native habitat is rainforest rather than the more infertile sites colonised by the Australian heathland Proteaceae. An indication of the cosmopolitan nature of this species is that Willson *et al.* (1975) commented on the shading effect of large *G. robusta* trees growing in Kenya. It appears to be a fairly adaptable species. Hockings (1970) states that, in general, grevilleas prefer a soil with definite acid reaction but that there are two quite well known exceptions, *G. robusta* and *G. striata*, both of which can thrive in alkaline soils.

G. robusta can be grown successfully as a pot plant and JIP2 was recommended for potting-on from 7 to 12cm pots (Anon 1962). Moore and Keraitis (1966) grew this plant in perlite using nutrient solutions. They noted a positive NK interaction with many growth parameters. Potassium enhanced the dry matter yield of leaves but this occurred mainly at the highest N rate. Perlite itself has very low nutrient levels (Morrison *et al.* 1960) while the medium used in the present study contained 20 - 60 ppm K at 2 months when supplied with 25g K/m^3 from the slow release Osmocote base dressing (Table 8, Chapter 2). The high rate of K was presumably not required although it is surprising that the low rate was adequate when 450g N/m^3 was applied. There was certainly strong foliar uptake with high K fertilisation while the depression of foliar K with high added N probably indicates the need for both nutrients together.

Protea repens

Nitrogen and phosphorus both strongly influenced growth while potassium had no statistically significant influence (Table 1). It is quickly apparent that the high P rate was highly toxic and even 5 weeks after potting severe toxicity had occurred which eventually resulted in the death of all plants receiving 300g P/m^3. Initially P toxicity was more severe in the presence of high N levels than in the absence of N (Table 2) which is a similar response to that of *Grevillea rosmarinifolia* (Chapter 2). The N rate was clearly too high for this protea and growth was depressed by high N in all 3 ratings. The tops of the shrubs were initially burnt back due to high N and it wasn't until the latter part of the experiment that new growth occurred in these treatments but was insufficient to give a significant dry weight increase.

Foliar levels of nutrients were markedly influenced by fertiliser treatments particularly by N and P (Table 4). Added N strongly promoted foliar N, Mg and Ca levels while Na was mildly increased and K uptake depressed. The effect of high P levels in the medium was outstanding and the uptake of all 6 nutrients was strongly promoted. Foliar levels of P were nearly 9X higher while all other foliar nutrients were doubled or close to this level of increase in treatments with high as compared with low P additions. Foliar P, K and Na were highest at P_1 K_1 and Ca and Na uptake at high N and P (Table 5).

Guidelines given for the culture of proteas indicate that potting media should contain little fertiliser (Werner 1951) and manure should not be dug around the roots when planting (Vogts 1954) but can be used around plants if applied to the soil surface (Stevens 1965). In essence these recommendations state that proteas will respond to low levels of fertilisation while high nutrient levels in the root zone must be avoided.

The most significant feature of the nutrition in their native habitat, (in common with the Australian Proteaceae) is that the majority of the South African Proteaceae are confined to deficient soils, for instance Table Mountain sandstone (Johnson and Briggs 1974). Some species extend into the summer rainfall region but live on siliceous formations (Rourke 1972) while others may occur further north on deficient soils such as quartizites on old mountain formations (Wild 1968). *Protea repens* is from lower levels and is more tolerant of fertile soils than higher altitude species (Brits 1978, pers. comm.). Parvin *et al.* (1973) discussed the culture of the Proteaceae and stated that knowledge of the native environment of proteaceous plants has provided little guidance to their nutrition. They went on to say that recommendations varied from no fertilisation (Eliovson 1967) to a "standard" fertiliser program (Watson and Parvin 1970). This statement by Parvin *et al.* (1973) appears to indicate a lack of understanding of the requirements of these plants and the reports on their native habitats. They observed nutritional disorders in several protea species and noted that foliar Ca levels were consistently low in unhealthy plants while P was also low compared to those obtained for other Proteaceae (macadamia) (Cooil *et al.* 1966). This was an unjustified comparison since macadamia is not only in a different sub-family but occupies a very different habitat - it is indigenous to the Queensland rainforest (like *Grevillea robusta*), and recent unpublished research in this department indicated macadamia to be tolerant of quite high fertility conditions, including high P.

Van Staden (1968 b) found that, with the exception of K, Ca and in two instances N, deficiencies of major nutrient elements had relatively little effect upon the growth of *P. cynaroides* grown in pots containing sand. Deficiencies of K and Ca resulted in a reduction of almost all measurements of root and foliage growth, while N deficiency only affected dry weight yield of leaf and root. An absence of P, Mg, S and Fe from the nutrient solution had no significant effect. These results indicate that this protea is very tolerant of extremely low P levels and quite tolerant of a lack of N and therefore able to grow under a very low general plane of nutrition providing K and Ca are not too low. These results help to explain the sensitivity of *P. repens*, in the present study, to high N and P levels since the plant appears adapted to very low levels.

Foliar P levels of a range of samples taken from *P. neriifolia* growing on 3 sites in Hawaii ranged from 0.03 to 0.12% (Parvin *et al.* 1973) while Van Staden (1968 b) observed levels between 0.003 and 0.009g%. These figures are all below foliar P levels found in the 30g P/m^3 treatments in the work reported here. The high P treatment which was highly toxic produced foliar P levels 10 times greater than Parvin *et al.'s* highest figure and 150 times that of van Staden.

Parvin *et al.* (1973) noted that unhealthy proteas with red colouration in the leaves had low foliar Ca levels (0.2 or 0.3) compared with healthy leaves (0.5%). Van Staden (1968 b) found that severe chlorosis and necrosis was related to low Fe content induced by deficiencies of N, K, Ca or Fe in the medium. Foliar Ca levels exceeded 0.5% and no chlorosis was observed in the present study. Added P had a very strong and outstanding promotive influence on the uptake of all nutrients while van Staden (1968 b) surprisingly found that it only significantly enhanced foliar K and Ca.

Camellia japonica

Initially this plant showed intolerance to the high N rate and foliage growth was depressed after 2½ months (Table 1), which was made slightly more severe in the presence of high K (Table 2). An increasingly strong N response was evident at 6½ and 9½ months, particularly in dry weights (Table 2), and it was noticeable that this was inhibited by high P in the visual ratings. High P also strongly suppressed the dry weight response to N.

High N fertilisation increased foliar N, Mg and Ca, and was antagonistic to K uptake (Table 4). High P levels generally promoted nutrient uptake. They increased the foliar levels of P, K, Ca and Na ($P = 0.06$). The influence of added P on foliar P was strongest in low N and most promotive for foliar Ca when added K was low (Table 4). High K fertilisation increased foliar K levels and depressed Mg uptake (Table 4) but appeared to have no other significant influence.

Table 3 gives the response of camellias to additional treatments involving very high NPK levels and one with no fertiliser applied. Plants were surprisingly tolerant of the latter and conversely severely damaged when N, P and K were all at very high levels. Very high P and K (600 and 500 g/m^3 respectively) were slightly less phytotoxic (dry weights) than when high N was also present. Excessive levels of NH_4-N, P and soluble salts (see Tables 7 and 8, Chapter 2) probably caused the supressed growth. The very high N levels (additional treatment 1) were inferior to nil rate (along with the very high P, K and NPK treatments) at 2½ and 6½ months. By the end of the experiment (after 12 months) nitrification would probably have converted much of NH_4-N to NO_3-N and would account for this treatment yielding higher dry matter yields than other additional treatments and all factorial treatments (although there was no combined analysis with the latter). Growth would therefore have occurred in the latter part of the experiment and plants in the very high N treatment were able to use the prolonged availability of N despite the initial excessive levels. No slow release N sources were used in this experiment.

Camellias have a relatively slow growth rate, are intolerant of moderate salinity levels (Furuta 1969), and are susceptible to injury by excessive fertiliser levels (Pearson 1958, Wills 1971). This was confirmed in the present study where high N and P were mildly toxic at various stages. The high total N levels and excessive soluble salts were probably the main causes of growth suppression since tea (*C. sinensis*) (and probably *C. japonica*) has been shown to have a preference for NH_4-N rather than NO_3-N (Ishigaki 1974 and 1975, Ishigaki and Hoshina 1977, and Selvendran and Selvendran 1973). It was also noticeable, in the work reported here, that luxury uptake of nutrients readily occurred with *C. japonica* particularly with high P fertilisation. This would help to account for the plants observed sensitivity to high N and P and probably indicates an innate ability to extract scarce nutrients from the soil (and consequently very high nutrient levels in nursery media should be avoided). They may have evolved in a woodland habitat which was generally fairly infertile.

The main growth response was to N and it has been noted by several workers that this is the most important element for *C. japonica* growth (Bonner and Honda 1950, Furuta *et al.* 1954, North and Wallace 1966, Bates 1971). Moderately high N plus simply adequate P and K were found the most suitable combination for the nutrition of high quality flowering *C. japonica* plants (Scott 1977).

Increased N fertilisation, particularly NH_4-N (Ishigaki 1974, Ishigaki and Hoshina 1977) gives a proportional increase in foliar N levels in tea (Willson 1975 a). Antagonism with NH_4-N *v* K and K *v* Mg were noted by Ishigaki and Hoshina (1977). N fertilisation can depress foliar K, Mg and Ca, while added P levels can increase Ca uptake especially if K additions are low (Willson *et al.* 1974, Willson 1975 a, b). These relationships were substantially confirmed in the present study indicating, perhaps, the similarity between the two camellia species.

Zurbicki and Shtraussberg (1964) considered that foliar N levels in tea have a rather stable optimum of around 4.7% and that whenever N fertilisation was highly effective it was always accompanied by a considerable increase in foliar N levels. Willson *et al.* (1974) and Willson (1975 a, b, c, d) gave the following nutrient contents for tea foliage:

<u>% Leaf Dry Matter</u>

N	2.9 - 4.9	Mg	0.16 - 0.21
P	0.22 - 0.25	Ca	0.3 - 0.4
K	1.68 - 1.72		

The P and K levels were similar, N was not as high, and Mg and Ca much higher for the foliar analysis of *C. japonica* reported here. The low N levels in Experiment C compared to foliar uptake found by Willson probably indicate that the N supply was not of sufficient duration to maintain foliar N at comparable levels. Mild N deficiency could have occurred in the latter part of the experiment since N fertilisation was primarily from short term Osmocote. Foliar Mg and Ca indicate that the supplied dolomite and carbonate of lime provided ample quantities of these elements when used at 6kg/m^3 (3:1 ratio).

Lycopersicon esculentum 'Best of All' (tomato)

Tomato was a highly responsive species and particularly to N and K fertilisation (Table 1). Growth was almost non existent at low N while K was very promotive at and after 2 months. The plants at 1 month indicated their essential need for high N and highest visual grades occurred at N_1 P_0 K_1 (Table 2). There was a response to P if this was coupled with high K and low N. A similar relationship remained at 2 months but high P merely reduced the N response in dry weights (Table 2). Foliage growth was strongly stimulated at high N and K in both ratings and particularly dry weights. Little response to K occurred with low N additions but strong synergism occurred when both were at high levels.

The influence of NPK fertilisation on foliar nutrient levels in tomato was just as dramatic as the growth responses (Table 4). High N fertilisation strongly promoted foliar N particularly at K_0 (Table 5). Foliar Na was also increased (Table 5) as was Mg, if added K was at low levels. Uptake of Ca was depressed by high N supplements.

The high rate of added P increased the uptake of N and Ca but foliar P and Na were only enhanced if N and P additions were both high (Table 5). High P fertilisation depressed Mg uptake. High K fertilisation reduced the level of most nutrients except foliar K which was more than doubled (Table 4). Reduced levels of all other nutrients occurred with high K fertilisation although this depended on the presence or absence of added N in the medium (Table 5).

The additional treatments given in Table 3 emphasise the need for, and tolerance of, very high nutrient levels in tomato compared to other species. Nil levels of nutrients prevented growth while even a medium level of balanced nutrients supplied from slow release Osmocote (18/2.6/10) were clearly inadequate to sustain rapid growth. Very high NPK levels individually applied and combined (Treatment 4) did not produce significantly different visual ratings between each other and it was noticeable that the foliar dry weight did not respond to very high N in the absence of additional high levels of P and K. The very high NPK level (Treatment 4) was superior to the latter and presumably the beneficial effects of a positive NK interaction overcame the problems of high NH_4-N in the medium (Table 7, Chapter 2). All very high nutrient levels (Additional Treatments 1-4) yielded dry weights which greatly exceeded the factorial treatments and while there was no combined statistical analysis the high nutrient requirements of tomato was clearly demonstrated.

Tomato crops remove large amounts of N from the soil and the rates of K required by glasshouse tomatoes are higher than for any other horticultural crop, and up to ten times higher than for many field grown crops (Winsor 1973). Brundell *et al.* (1975 a) reported on a series of nutrition and media experiments for soilless culture of tomatoes under glass in New Zealand. These crops indicated the need for N and K in the base fertiliser along with dolomite and serpentine superphosphate. Care is needed to avoid soluble salts problems in peat modules. Their base fertiliser recommendations for peat modules were a total of 245g N/m^3 and 482.6g K/m^3 from calcium nitrate and potassium nitrate. It was therefore not surprising that similar N and K rates were highly satisfactory treatments in the factorial part of the experiment reported here.

Fisher (1969) used liquid feeds containing 340 ppm and 57 ppm in an experiment to study the effect of N supply during propagation, on subsequent fruit production. The high N treatment produced more rapid vegetative growth and an increased early crop compared to the low level. High fertiliser levels can reduce the growth of container grown tomatoes in winter when light levels are low in Europe (Bunt 1969, Woods *et al.* 1968). This was most severe where high rates of N and Ca were combined with low rates of P (Bunt 1969). It was also found that the peat/sand (1:1, vv) mixture used was deficient in available nitrogen but that increased N levels were more likely to reduce growth with this medium in winter, than when a loam mix was used. In summer the position was reversed and there was a positive response to each increment of N in the loamless medium and growth was significantly greater than in the soil mix.

Brundell (1975 b) reported on work on propagating composts for tomatoes in New Zealand. Kinsealy and G.C.R.I. composts were considerably better than the loam based JIP2 compost in summer but these effects were much less marked in winter. The experiment reported here was conducted in mid winter but it appears that propagation media can be similar for both winter and summer in New Zealand. Experiments conducted in winter in England need to be interpretated with caution probably due to the pronounced effect of low light levels.

CONCLUSIONS

The comparative nutrition of the four species used in the experiments here, indicated widely differing requirements. The tomato was outstanding for its high fertility needs and ability to grow satisfactorily when the supplied NPK levels were 900-600-500 g/m^3 respectively. This contrasted with the protea which was injured by levels well below these. *Grevillea robusta* appeared to have the most similar nutritional requirements to tomato because of its high N needs while camellia showed intolerance of N and P resembling protea more than the other two. Tomato differed from the others in its very strong foliage growth response when high levels of N and K were combined.

Genotype is a key aspect of comparative nutrition and the tomato has been bred and selected to grow rapidly and fruit strongly in response to high levels of inputs including nutrients, temperature, light etc. and it differs greatly from its ancestors (Winsor 1973). The two intermediate plants have evolved in forests and *G. robusta* contrasts with camellia and *G. rosmarinifolia* (Chapter 2) in that it comes from a relatively fertile habitat while grevilleas from the Australian heathlands have evolved on impoverished soils. Camellia was initially intolerant of high N (especially at N_1 P_1) and it is probable that the temperate forests in which this plant developed were not very fertile. A further aspect with camellia is that it does not appear to have a very rapid growth rate compared to tomato or *G. robusta* and this may be linked to its native habitat (wooded hillsides in S.E. Asia: Threlkeld 1962) since it often grows there at quite high altitudes (900-1200 m) (Creech 1958) and would not be expected to grow very rapidly; *C. japonica* is the hardiest of the cultivated camellias (Synge 1956). Protea was least able to tolerate high N and P levels and this reflects the highly infertile soils of its native country. A similar correlation between growth response to added nutrients and genotype was indicated where nil or low nutrient levels were used. At one end of the group was tomato which was highly intolerant while protea was only grown without toxicity symptoms with under 50g of N and P per m^3. The implication that plants sensitive to high fertilisation can tolerate low levels is, however, not always reliable since *G. rosmarinifolia* (Chapter 2) was quite highly intolerant of very low N yet sensitive to very high N, and high N and P together.

CHAPTER 4

NUTRITION OF CONTAINER GROWN *HAKEA LAURINA* R.BR., *LYCOPERSICON ESCULENTUM* MILL. 'BEST OF ALL' (TOMATO) AND *GREVILLEA ROSMARINIFOLIA* A. CUNN. IN SOIL AND SOILLESS MEDIA SUPPLIED WITH VARIOUS SLOW RELEASE FERTILISERS

ABSTRACT

Five experiments were run to study the influence of media and fertiliser sources on the growth of 3 container grown species. Tomato had the highest nutrient requirements and greatest tolerance of potentially toxic rates, grevillea was intermediate and hakea preferred low levels such as NPK 45/30/25 in combination with a soil medium. Tomato foliage growth was equally prolific in peat/perlite (PPl) (1:1, vv) or soil/peat/perlite (SlPPl) (1:1:1, vv) when supplied with NPK 450/300/250 or 900/600/500 however root growth (in both experiments) was superior in PPl. Growth in soil media, in all experiments, was generally greater than in PPl at very low or nil fertiliser rates. Toxic levels of NPK from Nitrophoska were more severe on tomato in PPl than SlPPl or peat/sawdust/vermiculite (PSdV) (1:1:1, vv) but increasing the proportion of soil in PPlSl media did little to alleviate depressed top growth in grevillea or hakea caused by combinations of P and N or K. Grevillea and hakea foliage growth was generally strongest at high N coupled with low P, K and added soil levels. The negative NP interaction was stronger in hakea than grevillea, while K was promotive for grevillea only. High P fertilisation strongly promoted nutrient uptake in grevillea.

INTRODUCTION

The difference in the behaviour of the principal plant nutrients when applied to a peat-sand compost and a mineral soil mix (John Innes) was discussed by Bunt (1976). It is clear that the results of nutrition studies will vary with the physical and chemical aspects of the medium itself, as well as with types of fertiliser and their rates of application. Goh and Haynes (1977 a) described the physical and chemical characteristics of various soil and soilless media and found that growth of aster varied with different media and N sources. Haynes and Goh (1977b) noted that in soilless media plant recovery of N from Osmocote (26% N) was about 10% above those for IBDU, sulphate of ammonia and urea but in the soil medium, percent N recoveries from all fertiliser treatments were similar. The mean percentages of N immobilisation were 39 for peat-sand, 54 for peat-sand-sawdust and 18 for peat-sand-soil.

The previous two chapters (and subsequent ones) describe nutrition studies based on peat/sand or peat/perlite (both 1:1, vv) supplied with Osmocote (26% N), superphosphate and sulphate of potash. The objective of the work described here was to use different media and fertiliser sources from those used in other trials, to further compare nutrition of different species. Soil-mixes rather than soilless media were predominantly used.

MATERIAL AND METHODS

Plant Species and Growing Conditions

Five experiments were carried out with tomato seedlings and 2 Australian shrubs. The plants used, laying down and harvesting dates and the number of replicates are given in Table 1. Only *Grevillea rosmarinifolia* was vegetatively propagated, and was raised from semi-ripe tip cuttings under mist. The *Hakea laurina* seedlings were potted-up into tubes containing very low nutrient levels, following initial propagation. The tomato seedlings were pricked - out directly into the treatments from seed boxes. All experiments were run in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Hand watering was done when required and no fertiliser applications were made following laying down.

Experimental Design, Media and Fertilisers

All experiments, except Experiment C, were designed as factorials. All were randomised block designs and Experiment C involved 19 separate treatments. Several media were used in combinations of peat (P), soil (Sl) and Vermiculite (V) in the 5 experiments described here. Sphagnum peat was used in all experiments either from Dipton in Experiments A and B or from Mataura in all others. Physical and chemical properties of both peats were described by Goh and Haynes (1977 a). Perlite (Pl) was a fine grade material as described by Morrison *et al.* (1960) and the soil was Wakanui clay silt loam taken from the top 15cm of cultivated ground. The soil's characteristics were as follows: pH 5.9, soluble P 5%, organic C 3.1%, total N 0.18%, C/N 17, Cation Exchange Capacity 10.3 me /100ml , total bases 5.4 me /100ml and base saturation 52.4%. The properties of vermiculite were described by Bunt (1976) and the material used was horticultural grade (number 2) exfoliated in New Zealand. The sawdust was a coarse grade material as used and described by Goh and Haynes (1977 a).

The levels of N, P and K used for Experiments A and B are given in Table 2; Table 5 for Experiments C and Table 6 and 11 for Experiments D and E. The nutrients for Experiments A, B, D and E were supplied from a basal dressing of 0.25 kg/m^3 of Osmocote 18/2.6/10 (except 'nil' treatments for Experiments A and B) with additional levels of N, P and K supplied from Osmocote 26% N, superphosphate (9% P) and sulphate of potash (39% K) respectively. All treatments for these 4 trials also received a basal dressing of the following: 4.5kg/m^3 dolomite lime, 1.5 kg/m^3 agricultural lime ($CaCO_3$), 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.20% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The nutrients and basal dressing for the Osmocote treatments in Experiment C were identical to the other 3 experiments. The last 11 treatments in Experiment C were based on Nitrophoska. The media and fertilisers were well mixed and then transferred to PB5 (2½l) 'Plantabags'.

The pH level (mean of 2 samples) were sampled after 30 weeks for *Grevillea rosmarinifolia* (Experiment D) and indicated that the high fertiliser levels (particularly N) mildly to moderately acidified the media as follows:

pH Of Media

NUTRIENTS (g/m^3)			Soil : Peat : Sand (vv)		
N	P	K	1:2:2	1:1:1	5:2.5:2.5
45	30	25	6.7	6.4	6.5
450	300	250	6.4	5.9	5.8
400	600	250	-	6.1	-
450	300	500	-	5.8	-
900	300	250	-	5.5	-
900	600	500	-	5.5	-

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Data Collection and Analysis

A range of soil analyses were carried out 5 weeks (22/11/72) after potting-on the last 9 treatments in Experiment C. Three samples of 3cm diameter to a depth of 8cm were obtained, aggregated together and mixed to give a composite sample which was then sent to 2 organisations. Soil analyses were carried out by Vautier Enterprises Ltd (now Water, Soil and Laboratory Services, Napier) who used Truogg extraction for P, K, Ca and Mg and soluble salts by the methods described by Metson (1956).

On completion of all experiments the plants were cut-off just above the top of the medium and the foliage oven dried. In Experiment B the tomato roots were extracted, carefully washed so that all medium was removed and then oven dried. All data was statistically examined using Teddybear (now Crypto/teddybear) computer programme for analysis of variance and F test. Additional treatments were used in Experiments D and E (Table 11) and were laid out in the same randomised blocks but analysed separately.

RESULTS

Experiments A and B

Tomato seedling foliage growth was generally greater in peat:perlite (PPl) than the soil mix while *Hakea* grew better in the peat:perlite:soil (SlPPl) medium (Table 2). Added nutrient levels played an important role in this response but the soil medium was superior for both plants when nil or NPK 45/30/25 treatments were involved (Table 3). Soil was therefore promotive at low levels of fertiliser additions. This was also the case for *Hakea* foliar dry weights while there was no significant difference between this data for tomato. There was no interaction between media and NPK levels for tomato root dry weights and root growth was greatest in the soil mix irrespective of nutrient additions (Table 2). *Hakea* had a higher foliar dry weight at NPK : 45/30/25 compared to nil levels when PPl but not SlPPl (Table 3). Foliar dry weights of *Hakea* were highest with nil NPK in the soil medium and high NPK levels were inhibitory.

Experiment C

The foliar and root dry weights for tomato seedlings grown in several media with a range of added nutrients is given in Table 4 and soil analyses in Table 5. Plants grown in PPl and SlPPl with a total NPK level of 450/300/250 supplied from Osmocote and SlPPl with NPK 900/600/500 also from Osmocote had higher foliar dry weights than in any other combinations. Next was PPl with NPK 900/600/500 from Osmocote. The third highest foliar dry weights were with treatments supplied with NPK 225/150/125 from both fertilisers and grown in PPl, SlPPl and soil:peat:vermiculite (SlPV). It was noticeable that media containing soil and supplied with NPK levels of 45/30/25 were all superior (foliar dry weights) to the PPl media irrespective of the type of fertiliser.

Plants supplied with the Nitrophoska at the 2 higher rates generally grew poorly and often had foliar dry weights similar to those given a total NPK of 45/30/25. An NPK of 450/300/250 supplied from Nitrophoska was much more toxic for plants in PPl than those in SlPV or peat:sawdust:vermiculite PSdV.

Root dry weights were highest in PPl supplied with the 2 middle rates of Osmocote. Next equal were PPl and SlPPl at the lowest and highest NPK levels respectively and PSdV and SlPV at the 225/150/125 nutrient rates. There was generally only a very minor correlation with foliar dry weights and it was noticeable that plants in PPl Osmocote had higher root weights than those in the corresponding soil mix with this fertiliser. This partly reversed the trends with the foliar dry weights. Generally those with very small foliar dry weight yields, also had low root weights.

Media analyses (Table 5) gave some indication of P and K levels found at 5 weeks in certain treatments. High superphosphate additions raised the Ca levels while high fertiliser levels moderately raised the soluble salts and depressed the pH as found for Experiment D (Materials and Methods) and in Chapter 2. Vermiculite contains Mg and this raised the concentration of this nutrient in mixes containing this amendment.

Experiment D and E

There were few main effects but many interactions when *Grevillea rosmarinifolia* and *Hakea laurina* were each grown in a 2^3 x 3 experiment involving NPK and 3 media (Table 6). Even the N main effect did not appear very strong and P was clearly phytotoxic for hakea.

The two factor interactions are set out in Table 7. There was a moderate to mild negative NP interaction for grevillea while this occurred much more strongly for hakea. Grevillea foliar dry weights were promoted by the presence of high P and K but with hakea these yields were highest in the absence of high P or K. High potassium depressed hakea foliage growth at low P and phosphate was very toxic at both K levels. There was also a mild negative NK interaction.

The strongest response to nitrogen by grevillea was in soil:peat:perlite (1:2:2) mix and it was noticeable that there was no significant N promotion in the other 2 mixes containing higher soil levels. Hakea also grew best in the mix with least soil and high N levels but where there were equal parts soil:peat:perlite (1:1:1) or 50% soil (5:2.5:2.5) the plants grew better at low N.

Foliar dry weights of grevillea were poorest with high P and in the high soil mix (5:2.5:2.5). High P did not reduce growth in the other 2 mixes where only these 2 factors were considered. Phosphate toxicity was equally severe in all mixes for hakea. The latter plant when supplied with low P had higher foliar dry weights in the two mixes containing the least amount of soil.

The three factor interactions given in Table 8 allow further appraisal of the growth responses of the 2 species. *Grevillea* grew most strongly at N_1 P_0 low soil and N_1 K_1 low soil and it appeared that high K can partly alleviate the toxic effect of high P since the mean foliar dry weight with P_1 K_1 low soil was superior to those with low P and high K in any mix. However this was not apparent for *Hakea* and the 3 factor interaction indicated that the optimum combination for this species was high N with low P, K and soil. Foliar analyses were only carried out for grevillea (Table 9). High N fertilisation increased foliar N levels but reduced the uptake of P, K and Na. High P additions promoted the uptake of all 6 nutrients. Uptake of N and Mg was strongly enhanced while the increase in foliar P was more than double and was tripled at N_0 P_1 (Table 10). High K in the potting mix raised foliar K levels but only at N_0 P_1. Antagonism between K and Mg occurred and foliar Mg was depressed by high K coupled with low P additions.

The additional treatments given in Table 11 indicated that grevillea was far more tolerant of very high nutrient levels in soil media than was hakea. Conversely hakea grew better than grevillea with nil added fertiliser and hakea had the highest ratings and dry weight in treatment 5. Foliar ratings of grevillea receiving no fertiliser were highest (equal to treatments 3 and 6) at 3 months and only equalled by the 450/300/500 treatment visual ratings at 6½ months, but at harvest the dry weight yields were less than those in the 2 other treatments. The very high N treatments (900g N/m^3) appeared to be relatively more toxic than high P for grevillea. This could partly be due to the fact that water soluble phosphate can be less available in soil than in soilless media (Bunt 1976). Greater P toxicity occurred with *G. rosmarinifolia* in PPl (Chapter 2) than in this experiment, also these plants grew well in 3 additional treatments containing 300g P/m^3 and 2 with 600g P/m^3. Added N fertilisers can yield equally high NH_4-N levels in soil or soilless media (Bunt 1976) and can be toxic (Haynes and Goh 1977) as found in Chapter 2. The 450/300/250 from slow release Osmocote was adequate for grevillea but toxic for hakea even though the theoretical supply would be 53g N/m^3/month.

Hakea was far more sensitive than grevillea to high nutrient additions and the only satisfactory additional treatment was the nil fertiliser treatment followed by 45/30/25 with PPl. There was no significant difference between plants grown in SlPPl or PPl at 450/300/250 and even the slow release fertiliser source at this level was less satisfactory than the nil rate.

DISCUSSION

Very high nutrient levels were more toxic to tomatoes grown in soilless media rather than soil (Experiment C). The proportion of soil in the medium, however, appeared to have little influence on reducing toxic nutrient levels used in Experiments D and E. Goh and Haynes (1977 a) found that the Cation Exchange Capacity (CEC) of P/S mixes was between 7 and 13 me /100ml while a mix with equal parts soil/peat/sand was 10-15 me /100ml (the variation in each case depending on type of peat). The effect of adding soil therefore only had a minor influence on the CEC. It was quite clear that excessive fertiliser rates for sensitive species must be avoided just as much in a soil mix.

Further factors need to be considered when comparing media. The increased porosity in soilless mixes or media with reduced proportions of soil appeared to be a more significant factor than buffering of high nutrient levels caused by a high CEC. Haynes and Goh (1977) noted a similar possible fertiliser-medium interaction and postulated that better physical properties caused by high porosity of certain media (Goh and Haynes 1977 a), encouraged root growth which in turn facilitated increased growth of tops and roots of asters in response to added nutrients. In agreement with this, Poole *et al.* (1968) observed that the growth and grade of *Hibiscus* and *Aralia* plants decreased as the proportion of soil in the media increased, which indicated that the presence of soil in the medium can reduce the desirable physical properties of a medium. Similarly Hayes and Simpson (1958) noted that plants grew better in JIP media when it was amended with vermiculite compared with the standard potting mixes.

Most of the materials used to make loamless composts either do not contain any significant amounts of nitrogen or, as in the case of peats that may have from 1 to 3% of the dry weight as organic nitrogen, it is in a form which is not readily available during the life span of the average pot plants (Bunt 1976). Haynes and Goh (1977) found that the foliage growth of asters was greater in a medium consisting of equal parts (by volume) peat/sand/soil than with soilless media such as equal parts peat/sand when no nutrients were added. They attributed the difference in growth to the readily available (native) N present in the soil initially. This would account for the poor performance of plant species, especially tomato, in soilless rather than those media containing soil in these experiments. In some cases there was even improved growth with increasing soil levels when added N was low. This had practical implications for the longevity of pot plants in the home and it is noteworthy that of the two principal house plant producers in New Zealand, one uses PP1 while the other wholesales plants in a S1PP1 medium.

The tomato is a herbaceous plant which is well known for its high nutrient requirements and hence its strong general nutritional response and tolerance of very high nutrient levels was not unexpected. The highest dry weight yield of tops occurred in the presence of Osmocote which would have released approximately 250g N/m^3 in the first month. Bunt (1976) states that the maximum amount of mineral nitrogen that can safely be added in the base fertiliser is only of the order of 200 to 250 g/m^3 and presumably not all of this would be available in the first month.

Grevillea and hakea clearly have much lower nutrient requirements than tomato but it was surprising to observe quite strong differences in growth response and sensitivity to high N and P additions between the two genera. Further aspects of the nutrition of the latter will be discussed in Chapter 6. It was, however, noteworthy that *Grevillea rosmarinifolia* showed very similar foliar uptake levels in the work discussed here compared to when grown in peat/perlite (1:1, vv) (Chapter 2). The factors governing nutrient uptake and often the absolute levels were almost equal, even though different media were used.

CHAPTER 5

NUTRITION OF CONTAINER GROWN ACACIA VERTICILLATA (L'HERIT.) WILLD. 'REWA', BORONIA MEGASTIGMA BARTL. CHOISYA TERNATA H.B. AND K., EUCALYPTUS NOTABILIS MAIDEN AND E. VIMINALIS LABILL.

ABSTRACT

The nutrition of 4 container grown genera of trees and shrubs (3 Australian and 1 Mexican) were studied. Plants were grown in peat/perlite (1:1, vv) in factorial experiments (with additional treatments) based on varying levels of Osmocote (26%N), superphosphate and sulphate of potash.

Foliage growth of acacia and boronia was strongly promoted by high N fertilisation with the latter being more intolerant of low levels. Compared with low additions, high % added P depressed growth, particularly when coupled with high N and more than doubled foliar P levels in both plants similar to the excessive luxury consumption in P intolerant Proteaceae. Choisya and 2 eucalypt species responded strongly to added N and foliage growth was poor at very low levels. Choisya was not damaged by very high P additions and there were no indications of luxury uptake. Foliage growth of the 2 eucalypts was not promoted by high added P but foliar P was strongly increased.

INTRODUCTION

Earlier chapters reported on the NPK nutrition of proteaceous shrubs and a few Northern Hemisphere plants. Australian plants in the Proteaceae inhabit infertile sites and it has been shown by the work reported here and by several others that they are intolerant of high fertiliser regimes particularly those associated with P. Other Australian plants are faster growing, such as the Mimosaceae but are less able than the Proteaceae to cope with very infertile soils (Lamont 1973).

Some species of acacia are reported as being highly adapted to environmental extremes. *Acacia harpophylla* can tolerate extremely saline conditions (Gates 1972) while *A. obtusata* may be highly adapted to very infertile soils and was found to be extremely intolerant of high P levels in the medium (Frolich *et al.* 1966). Acacia will respond strongly to nitrogenous fertilisers (Fairall 1970) and mycorrhizas may give improved growth of container grown plants by inoculating steam sterilised potting media (Johnson and Michelini 1974). Boronias can also tolerate quite harsh conditions including very alkaline soils (Alcock 1976, Lindross 1977) although some dislike a high pH (Fairall 1970). Choisya is in the same family as boronia (Rutaceae) but is native to Mexico and reported as being adaptable to a wide range of conditions (Harrison 1960).

Pryor (1975) states that eucalypts are very sensitive to nutrient status which is related to their nutrient cycling and nutrient balance in natural stands. They have been shown to respond strongly to fertiliser N and P (Cromer *et al.* 1975, McIntyre and Pryor 1974) although high levels may cause excessive lush growth (Fairall 1970). Kaul *et al.* (1966 a, b, 1968, 1970 a and b) also indicated the importance of N and P since deficiency symptoms on a range of species were generally much more severe with these 2 elements rather than with K. Genotype and ecological adaptation appear very significant in the nutrition of this genus. This was demonstrated by species preference for specific forms of N (Moore and Keraitis 1971), ability to tolerate calcareous media (Parsons and Specht (1967), Ca requirements (Moore 1961), and differing ability of a range of species to assimilate several macro-nutrients (Anderson and Lidges 1978). They appear to have the ability to survive with very low P levels (Attiwill 1964) which may often be mediated by the presence of mycorrhizas (Malajczuk *et al.* 1975). Eucalypts are also often extremely tolerant of low micro nutrient levels (Pryor 1975).

MATERIALS AND METHODS

Plant Species and Growing Conditions

Four experiments were carried out involving 1 Mexican and 3 Australian genera including 2 species of *Eucalyptus*. The plants used, laying down and harvesting dates, and number of replicates are given in Table 1. All plants were raised from seed except *Choisya* which was grown from semi-ripe tip cuttings under mist. The young plants were potted up individually into tubes containing a medium with very low nutrient levels. The *Acacia* (Experiment A) and *Eucalyptus* (Experiment D) trials were carried out in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above the ambient temperature. The *Boronia* (Experiment B) and *Choisya* (Experiment C) trials were run in a shadehouse covered with 50% polypropylene shadecloth (Sarlon). Hand watering was done when required and no additional fertiliser applications were made following laying - down.

Experiment Design, Media and Fertilisers

All experiments were 2^3 NPK factorials using the rates and number of replicates given in Tables 1 and 2. All were randomised block designs. Additional treatments were used, as in Experiment A, Chapter 2, and were laid-out alongside the factorial treatments within the same randomised blocks. Additional treatments were not included in the factorial analysis and Duncan's Test was used instead to assess significance. The medium for all experiments was equal parts (1:1, vv) Mataura sphagnum peat and fine grade perlite. A base dressing of 0.25 kg of Osmocote 18/2.6/10 was used for all treatments. Additional rates of N, P and K were supplied from Osmocote (26%N), superphosphate (9% P), and sulphate of potash (39% K) respectively.

Three of the additional treatments for Experiment A and one for Experiment B were based on the following alternative slow release fertilisers: 8-9 month Osmocote (18/2.6/10) or Floranid Nitrophoska (20/2/7) or Uramite (38% N), with additional P and K rates supplied as in the factorial treatments. Additional treatments, NPK rates and key to fertiliser sources are given in Table 3.

All treatments also received a basal dressing of the following: 4.5 kg/m^3 dolomite lime, 1.5 kg/m^3 agricultural lime (Ca CO_3), 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB 5 (2½ l) 'Plantabags' just prior to potting.

Data Collection and Analysis

Visual ratings of foliage were carried out using the grading system described in Chapter 2.

On completion of each experiment plants were cut-off just above the top of the medium and the foliage oven dried. All visual ratings and dry weights were statistically examined using Teddybear (now Crypto/ Teddybear) computer programme for analysis of variance and F test.

RESULTS AND DISCUSSION

Acacia verticillata 'Rewa' showed quite a strong response to nitrogen additions as indicated by visual ratings and dry weights of foliage (Table 2). This plant was quite tolerant of very low N levels and grew quite well with only 45g N/m^3 which would only amount to 5g N/m^3 per month when supplied from Osmocote 18/2.6/10. The visual appearance of the plants was depressed by 300g P/m^3 which is equivalent to 3.3kg of superphosphate per m^3. This was less apparent with the dry weights where there was only a 3 factor interaction which approached significance (P = 7%) (Table 4). In this case P depressed yield most severely in the presence of high N and K fertilisation.

The additional treatments also indicated the importance of nitrogen levels irrespective of the fertiliser source (Table 3). Treatment 1 yielded the highest foliar dry weights which was the highest N rate and based on 3-4 month Osmocote (26%N). This amounted to a theoretical supply of 257g N/m^3/month for the release period, but the dry weight was not significantly different in the presence of Uramite which was based on a lower total level of N, theoretically delivering 74g N/m^3/month for 6 months. The total level of 900g N/m^3 from 3-4 month Osmocote would have been expected to be quite toxic initially but by 9 months the foliar visual ratings were not significantly different from other additional treatments although growth in that treatment was still least at that stage. This position was reversed 2 months later at harvest when the dry weight was then greatest in Treatment 1 compared with other treatments although not significantly so. Slow release Osmocote would supply only 53g N/m^3/month while Floranid would release nearly 128g N/m^3/month but both these treatments were inferior to 900g of N from Osmocote (26%N). It is suggested that nitrogen supplied from fast release Osmocote had been removed in the last 2 months before lifting time and this would explain why the 900g N (double the total N level of additional and factorial treatments) resulted in dry weight yields which were much higher than all additional and factorial treatments, although not statistically analysed with the latter, even though 2 months earlier, growth had been inhibited in this treatment compared with others.

High N fertilisation appeared to have little influence on foliar nutrient levels other than mild but significant reductions in P and K uptake (Table 5) and a mild stimulation of foliar Na if added K was low (Table 6). High levels of P in the medium increased the foliar P levels by over 3 times while foliar Na was mildly reduced. Fertilisation with high levels of K promoted only this element in the foliage but also reduced the foliage Na.

Very high P uptake with high P fertilisation in acacia may indicate excessive luxury consumption which has been observed with proteaceous plants such as protea (Chapter 3). It could explain why foliar ratings showed that high P depressed growth although this was less obvious in the dry weight yields when leaching had probably diminished available P levels in the medium. Frolich *et al.* 1966 noted P toxicity on *Acacia obtusata* and that strong growth suppression was coupled with an increase of foliar P content from 0.49% to greater than 1.8% of dry weight with increased P fertilisation. They stated that these effects had not been observed on other *Acacia* species but it is reasonable to conclude that similar results may be observed in varying intensity on others in the genus, according to genetic and ecological origins of the different species. It is apparent that there are wide extremes within the genus as indicated by the work of Gates (1972) who described how *A. harpophylla* is capable of growing under extremely saline conditions - in excess of sea water concentrations - where most species are non-halophytic.

Boronia megastigma

Boronia visual ratings and dry weights of foliage (Table 2) displayed a strong response to nitrogen, particularly so with the latter. Plants given only 45g N/m^3 yielded much lower dry weights than those with 450g N/m^3, indicating an intolerance of impoverished N levels. Conversely, phosphate depressed both visual ratings and foliar dry weights although with the latter, depression was more severe at high rather than low N levels (Table 4). High potassium levels appeared to mildly depress the effect of N on visual ratings (P = 6%, table 4) but this was not apparent for foliar dry weights.

The data for additional treatments (Table 3) showed that additional levels of N, P and K were generally of no further advantage. Plant response to nil fertiliser levels were equal to those in the very high NPK level and in the inadequate slow release Osmocote treatment (No. 6, 53g N/m^3/month) at 4 months but by 11 months the dry weights, not surprisingly, were well below those in other treatments, where no NPK had been supplied. Growth in the very high N treatment No. 1 (900g N/m^3) was inferior to that in medium levels although no toxicity was observed at 4 months. The 600g P/m^3 treatment (No 2) produced equal growth and there was no P toxicity. It was however very noticeable that the NPK, 450/300/500 treatment (No. 3) promoted significantly higher foliar dry weights than all other additional treatments. High potassium may have had some beneficial influence in balancing the quite high P levels in additional treatment No. 3 (however no K response was indicated in the factorial part of the experiment). It is particularly noteworthy that 600g P/m^3 (Treatment 2) depressed the foliar dry weight below the 450/300/500 treatment; thus indicating P sensitivity in boronia.

The high rate of N strongly increased foliar N levels (Table 5) while uptake of Mg was increased at low P (Table 6). High N depressed foliar P and also K, providing that added P was low (Table 5). High P fertilisation increased N and Ca uptake (Table 5) while foliar P was more than doubled by high P fertilisation with low N additions and still strongly increased when coupled with high N (Table 6). High levels of K in the medium raised foliar K levels while N uptake was increased and Mg and Ca depressed over that in low K levels.

Choisya ternata

This shrub responded quite strongly to nitrogen and plants receiving the high N rate had much higher ratings and foliar dry weights than those on the very low level (Table 2). It was highly intolerant of a very low N regime, not noticeably responsive to P or K additions, and there were no significant interactions. Results from the two additional treatments (Table 3) supported the factorial part of the experiment since the very high N rate strongly promoted growth while the addition of 600g P/m^3 indicated that the plants were in very good condition at 3½ months and yielded high dry weights at lifting (15 months) and notably with no indication of P toxicity. The additional treatment with 900g N/m^3, equivalent to 257g N/m^3/month did not appear toxic after 3½ months and the foliar dry weight of plants from this treatment greatly exceeded all other treatments including factorial ones although no combined statistical analysis was carried out. The other additional treatment with very high P levels yielded the second highest foliage dry weights of all treatments. Choisya grew well at very high fertiliser levels and this at least indicates that this species is very tolerant of high P and contrasts well with acacia and boronia which both had depressed growth with even moderate P additions.

High N fertilisation increased foliar N particularly at low P, but at the same time foliar P was depressed (Table 5). High N levels depressed K uptake and mildly increased foliar Mg (P=7%). High levels of added P and K only mildly stimulated foliar levels of these elements. High P fertilisation also depressed K uptake but had no other significant influence.

Eucalyptus spp.

The two eucalypt species were strongly responsive to nitrogen as shown by ratings and foliar dry weights (Table 2). Yields in the latter case were nearly 6 times higher at the high, as compared with the low, N level. Growth was severely depressed at 45g N/m^3. The response to N additions, as shown by foliar ratings and dry weight was quite strongly depressed by high K for *E. notabilis* (Table 4); this was not apparent for *E. viminalis.*

High levels of N in the potting mix either stimulated or depressed the uptake of several nutrients as did K and to a less extent P fertilisation (Table 5). High N levels strongly increased foliar N (0.99 to 1.69 g%) particularly in the presence of high K additions (Table 6). Lamb (1977) also found a major response to N in eucalypts, which was predominantly a linear relationship between growth and foliar N over the range 0.68 - 2.04%N. Kaul *et al.* (1966 b) found that added K had a synergistic effect on the accumulation of N whereas varying dosages of N appeared to cause no specific trend in the uptake of K.

Uptake of Na (P = 6%) was also increased by high N levels while foliar Ca was reduced (Table 6). High N reduced foliar P particularly if added P was low. High P fertilisation strongly raised foliar P and also increased Mg and Ca uptake with the latter 2 only occurring at low N levels. High K additions depressed foliar P at N_0 and also reduced the uptake of Mg, Ca and Na. High K fertisation raised the levels of foliar K and therefore was generally antagonistic to nutrient uptake apart from with foliar N and K.

The importance of N and P additions to the potting medium was emphasised by Kaul *et al.* (1966 a and b, 1968, 1970 a and b) who found that a lack of these nutrients caused much more severe symptoms than K deficient media for a range of eucalypt species. Cromer *et al.* (1975) and McIntyre and Pryor (1974) noted strong foliage growth when open ground plants received N and P side dressings. The work reported here indicated an equally strong N response for both container grown species but no growth stimulation with high P levels although this treatment greatly increased foliar P levels. In explanation, it could be argued that different species were used and therefore comparison between species can only be very tentative. Genotype and habitat have been shown to influence N utilisation (Moore and Keraitis 1971), response to pH and Ca levels (Moore 1961, Parsons and Specht 1967) and notably the assimilation of macro nutrients such as P. Therefore if alternative species had been choosen for the experiments, they may have shown a growth response to added P. The lack of P response in the experiments reported here may also be accounted for by the fact that the low level was adequate and 300g P/m^3 was too high.

Soil analyses reported in Chapter 2 (Table 8) indicated that the medium with the low P treatment still had about 50-60 ppm available. This is a low level but Attiwill (1964) showed that eucalypt seedlings have a marked ability to survive with a low P supply and furthermore container grown plants were only responsive to low P additions. He found a 6 fold dry weight increase when plants were grown in forest soil and watered so that they received 30ppm P over the period of the experiment, whereas there was no further growth increase when 100ppm P was applied. Similar results were also obtained by Attiwill using sand culture where the largest response was to 1 and 5ppm P even though 10 and 50ppm levels of applied P were used. Various eucalypt species varied in their responses but were generally much more easily stimulated by added P than *Banksia serrata*. The response to N (30ppm) was strongest when combined with 30ppm P and this synergistic effect was more pronounced than when P was only added. Attiwill noted a strong correlation between supplied P and foliar levels, *Eucalyptus obliqua* plants not supplied with P in sand culture had a leaf concentration of 0.05 g% P and this rose proportionately to 0.14g% P at 50ppm of supplied P. In Experiment E the main effect of P indicated a rise from 0.33 to 0.71g% in foliar P of *E. viminalis* which displays a much higher level of feeding than that used by Attiwill (1964).

CONCLUSIONS

The four genera showed quite strong differences in nutritional requirements. Acacia and boronia responded in a similar manner to Australian heathland Proteaceae (e.g. *Grevillea rosmarinifolia*) in their sensitivity to P fertilisation. Choisya, the only non-Australian species - from Mexico, which although in the same family as boronia (Rutaceae) behaved quite differently to boronia and acacia. Native habitat appears to be more significant, in this case, than botanical relationship. High P additions depressed growth in acacia and boronia particularly in the presence of high N, and this resulted in luxury consumption so that foliar P levels were more than doubled. In contrast choisya foliar ratings and dry weights appeared higher with very high P levels (600g P/m^3) than with any of the factorial treatments (non statistical comparison). The 2 eucalypt species, the other Australian genus, showed no P toxicity and although foliar P levels in *E. viminalis* were strongly increased by high P in the medium there was no apparent toxicity.

Acacia illustrated the adaptable nature of the genus since there was a positive growth response to high N yet at low levels plants still grew well. The other species differed since they responded strongly to high N fertilisation but were intolerant of low N since growth was quite severely depressed, particularly with choisya and the 2 eucalypts.

CHAPTER 6

NUTRITION OF CONTAINER GROWN CALLISTEMON CITRINUS (CURTIS) SKEELS, GREVILLEA ROSMARINIFOLIA A. CUNN. AND HAKEA LAURINA R.BR.

ABSTRACT

Three Australian shrubs were grown in peat/sand (PS) (1:1, vv) potting media using a four factor central composite second order design in incomplete blocks to measure the response to N, P, K and lime, each at 5 levels. *Callistemon citrinus*, *Grevillea rosmarinifolia* and *Hakea laurina* showed very similar nutritional responses even though the former is in the Myrtaceae and not the Proteaceae. All 3 species responded strongly to N particularly in the absence of P. Hakea was most sensitive to P toxicity, then grevillea and finally callistemon. Optimum mineral levels for these plants in this media appear to be 50 - 100g P/m^3 , nil or low K and 3 kg/m^3 of lime which seemed most important for grevillea.

INTRODUCTION

The NPK nutrition of two proteaceous shrubs *Grevillea rosmarinifolia* and *Hakea laurina* was earlier studied using simple factorial experiments based on soil and soilless media (Chapters 2 and 4 respectively). *Callistemon citrinus* is an Australian shrub, included here for comparative purposes, although it belongs in the Myrtaceae. It has been established that Australian proteaceous plants inhabit infertile sites and have evolved so that they are intolerant to high fertiliser regimes, particularly those with high P. Other genera such as those in the Myrtaceae are faster growing but are less tolerant of very infertile soil conditions than the Proteaceae (Lamont 1973). Grundon (1972) established the controlling effect of soil fertility on the delineation of plant communities by showing that the Proteaceae has faster growth rates than other heath or introduced species only in very infertile conditions and that this advantage was soon lost if the nutrition plane was raised.

The first objective of these 3 experiments was to compare the nutrition of these 3 species and secondly to establish the nutrient response curves for N, P, K and lime and also the response surfaces of any interactive effects.

MATERIALS AND METHODS

Plant Species and Growing Conditions

The plant species, laying-down and harvest dates are given in Table 1. *Callistemon* (Experiment A) and *Hakea* (Experiment C) were seedlings but *Grevillea* (Experiment B) was propagated from semi-ripe tip cuttings under mist. Plants were potted - up, following initial propagation, into tubes containing a medium with very low nutrient levels. Experiment B was started under glass for a few months but was then moved into a shade-house. Experiment A was run in the same (as Experiment B) cloth - covered shadehouse (50% sarlon) for the entire period of the experiment. The *Hakea* experiment was carried out entirely in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. *Callistemon* received half an hour of watering every day by time - clock controlled, overhead sprinklers. The plants in the other two experiments were handwatered when required.

Experimental Design, Media and Fertilisers

These experiments were central composite designs (Box and Hunter, 1957) and involved N, P, K and lime with 30 treatments arranged in 10 blocks each consisting of 3 sub-blocks so that quadratic response curves could be calculated for each factor and for the derivation of two factor interactions. Each factor was present at five levels which were coded at -2, -1, 0, 1 and 2. This work therefore consisted of 3 experiments of 30 treatments x10 replicates i.e. 300 plants in each trial.

The medium used for all experiments was equal parts (1:1, vv) Mataura sphagnum peat and coarse manufactured sand. The physical and chemical properties of both media were described by Goh and Haynes (1977 a). The rates were as follows:-

Level	Nitrogen g N/m^3	Phosphorus g P/m^3	Potassium g K/m^3	Lime kg/m^3
-2	0	0	0	0
-1	150	100	83	3
0	300	200	166	6
1	450	300	250	9
2	600	400	332	12

Nitrogen was applied as a split dressing and the dates for the second half of the N application are given in Table 1. Nitrogen was all derived from Osmocote 26% N and the P and K from superphosphate (9% P) and sulphate of potash (39% K) respectively. Lime application was based on 3 parts dolomitic to 1 part (ww) agricultural lime ($CaCO_3$). All treatments received a basal dressing of the following: 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB5 (2½l) 'Plantabags' just prior to potting.

Data Collection and Analysis

Visual ratings of foliage were carried out at least twice during the period of each experiment and the heights of *Hakea* plants were also measured. The former involved the grading system described in Chapter 2.

On completion of each experiment the plants were cut-off just above the top of the medium and the foliage oven dried. All ratings, height measurements and dry weights were statistically examined using the Boxhu computer programme.

RESULTS

The constants and coefficients of response surfaces are given in Table 2. The coefficients of variation for all data in the 3 experiments were quite similar and mostly about 33%. Predicted values for main effects are given in Table 3.

Callistemon citrinus

This species responded strongly to nitrogen as indicated by the visual ratings after 4½ months and 1 year as well as the dry weights (Table 3). There was a strong (quadratic) response continuing up to a total of 450g N/m^3 particularly in the region of nil to 150g N/m^3. This result was apparent at 3 months and remained to be confirmed at the end of this experiment by the dry weight yields, however it was depressed by the presence of added P. This was a strong negative interaction as shown in Figures 1, 2 and 3 and was clearly apparent after only 4½ months. These effects did not show very strongly at the 13 month rating where the interaction only approached significance (P = 8%). Added phosphate tended to increase yields at low added N but the response to N was strongly depressed when both N and P were at high levels. A further negative interaction occurred between P and K but this only approached significance (P = 8%, Table 2). The optimum levels were 450g N/m^3, nil P and possibly low levels of added K and lime.

Grevillea rosmarinifolia

There was quite a strong response to N (Figure 4) particularly for foliar dry weight yields. The latter N response was only linear which probably indicates that added N was not fully adequate and had not reached the luxury range. This however, was only partially supported by the foliar visual ratings where the response shown in Figure 4 did indicate some flattening-out of the response curve between the 2 highest levels of fertilisation.

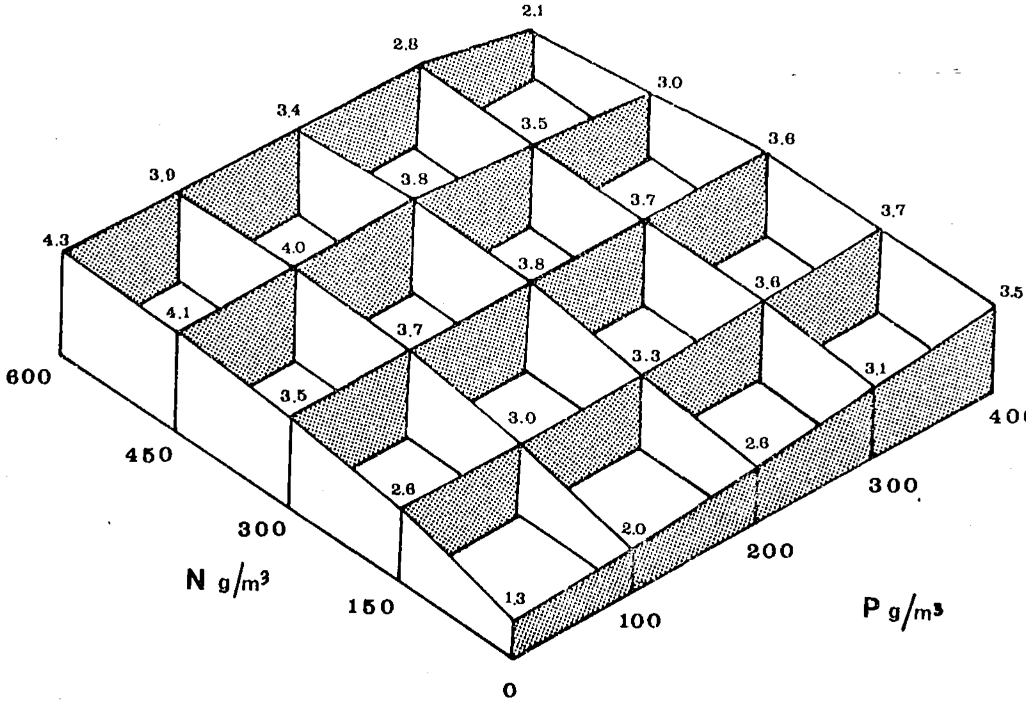

Fig 1: Expt. A. Interaction of N and P fertilisation on the foliage growth of *Callistemon citrinus*. Visual rating at 4½ months.

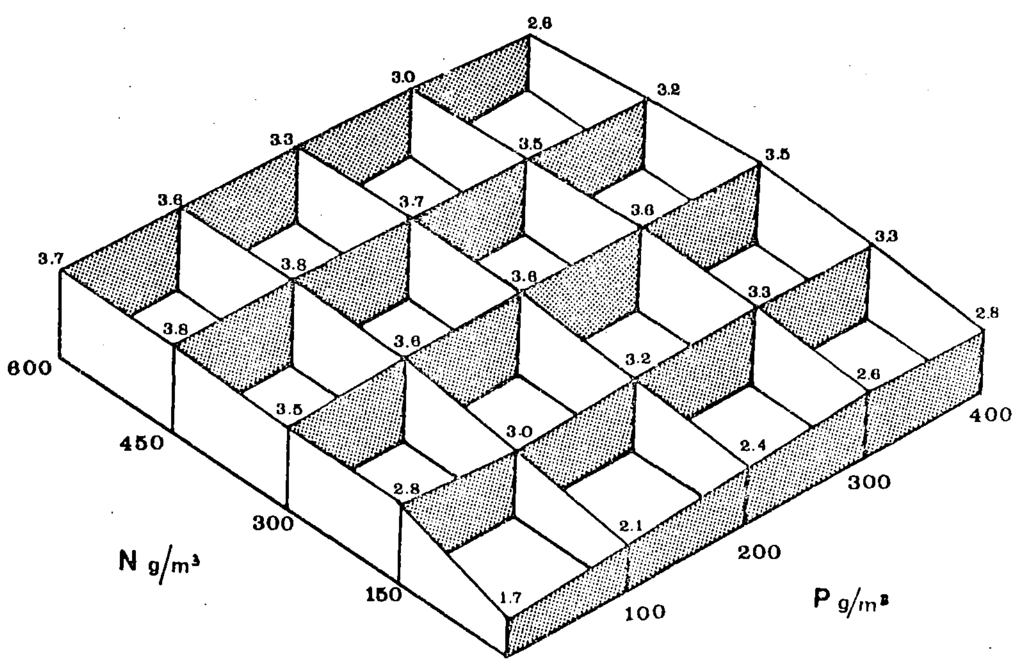

Fig 2: Expt. A. Interaction of N and P fertilisation on the foliage growth of *Callistemon citrinus*. Visual rating at 13 months.

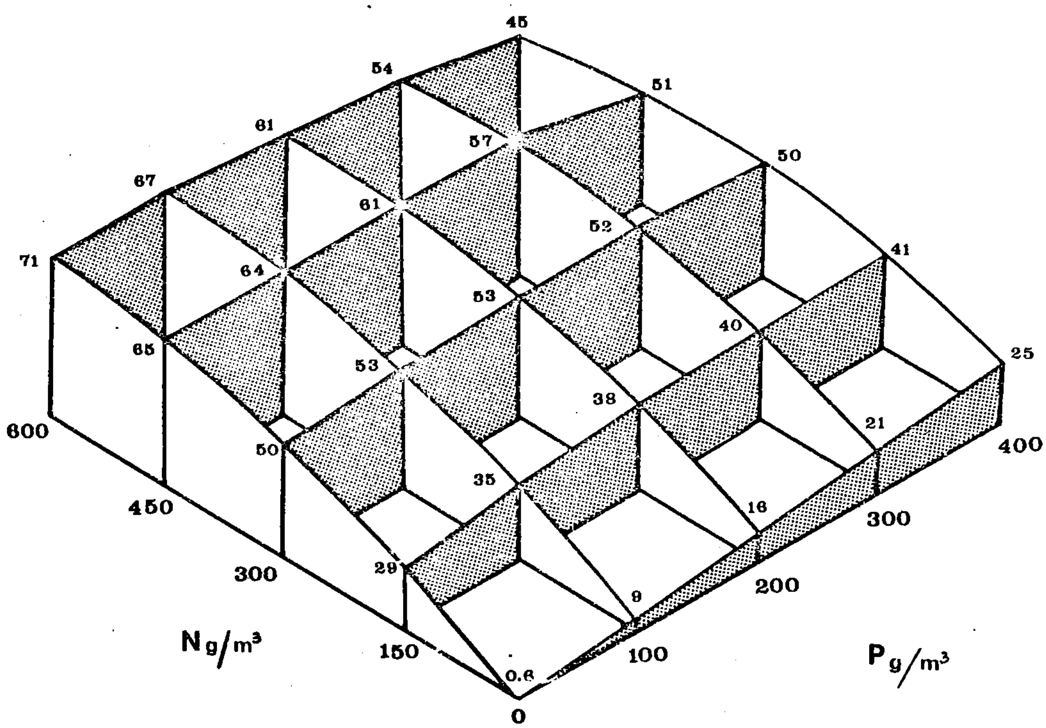

Fig. 3: Expt. A. Interaction of N and P fertilisation on the foliage of *Callistemon citrinus*. Dry weight: g/plt.

The response to P differed from N in that it was apparent after less than 2 months and in the first two ratings (Table 2) as shown in Figures 5 and 6. Severe P toxicity occurred at this early stage which gradually became less severe in subsequent ratings and dry weight data (Figures 5 and 7). Phosphate was much more toxic at high N rates as was apparent at the 2 month rating (Figure 6) and in the dry weight (Figure 7). More severe P toxicity at the beginning rather than later was probably brought about by the gradual loss of P, by leaching.

Lime had a minor effect on the influence of P and there was a significant interaction at the 7 month rating and was nearly significant after 3 and 10 months (Table 2). The pH in the medium was measured after 2 months. It was found that lime had a strong influence as illustrated in Figure 8 which approached the typical sigmoid response curve. High P and K levels had a mild acidifying effect. Figure 9 shows that the highest rated plants were those with lowest levels of P and lime, and that both factors depressed growth but less severely at the highest rate of the other. The optimum combination for growth appeared to be nil P and 3 kg/m^3 of lime. A small response to K was also recorded at 7 months but not found in any other data (Tables 2 and 3).

Hakea laurina

The third experiment yielded no interactions but there were very strong responses to N and P (Table 2). A strong positive response to N up to 300-450 g/m^3, was shown in the visual ratings, height and dry weight data (Figure 10). Plants at nil N were of very poor grade with low height and dry weight, and there was a strong quadratic response. This was equally strong but negative and quadratic for added P (Figure 11). Very severe P toxicity was apparent after 5½ months and this reamined the same in all subsequent data. The 450g N/m^3 and 50 to 100g P/m^3 appeared the optimum levels (Figures 10 and 11 respectively). There was a minor positive height

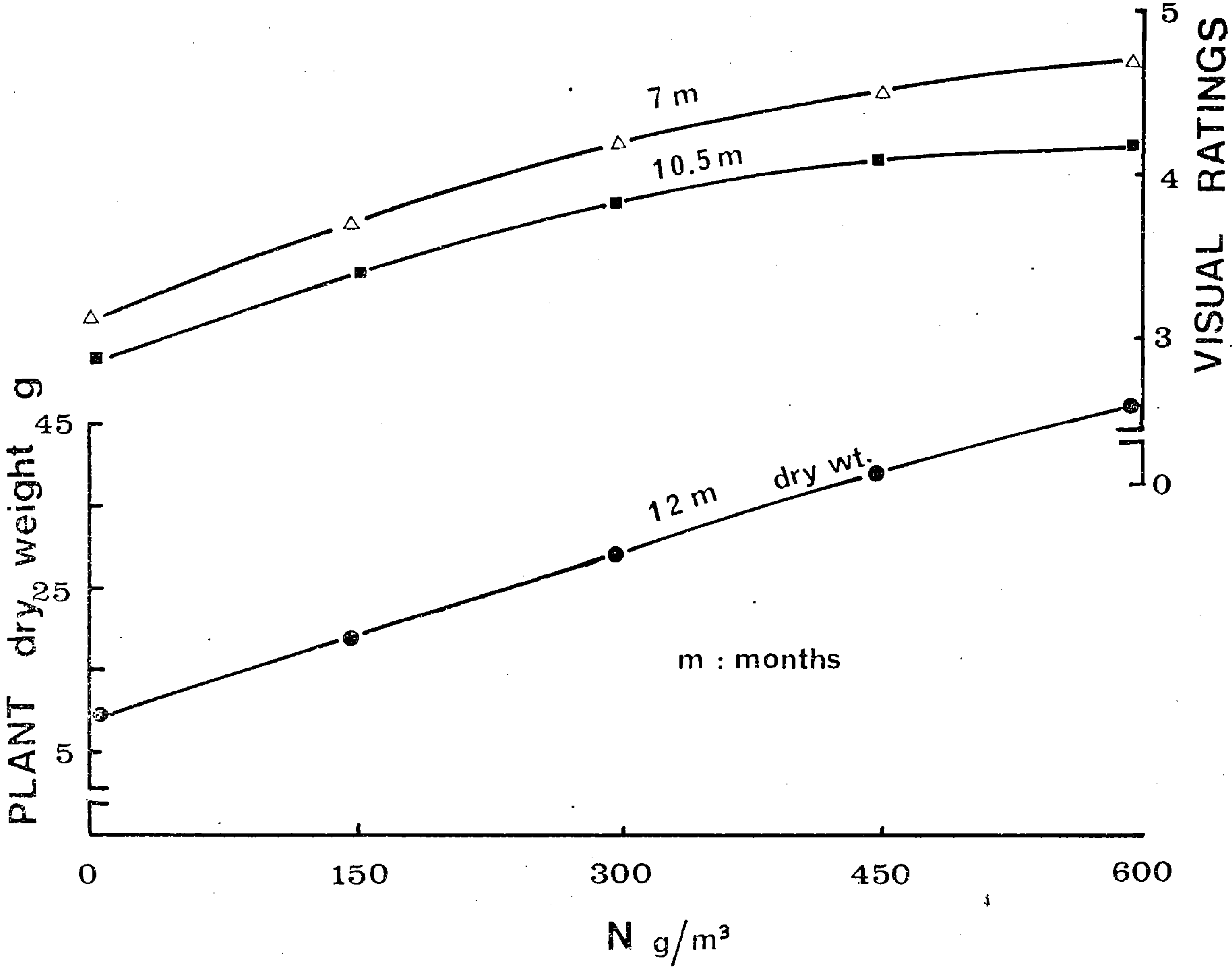

Fig 4: Expt. B. The influence of nitrogen on foliage growth of *Grevillea rosmarinifolia*. Visual ratings and dry weight (g/plt.).

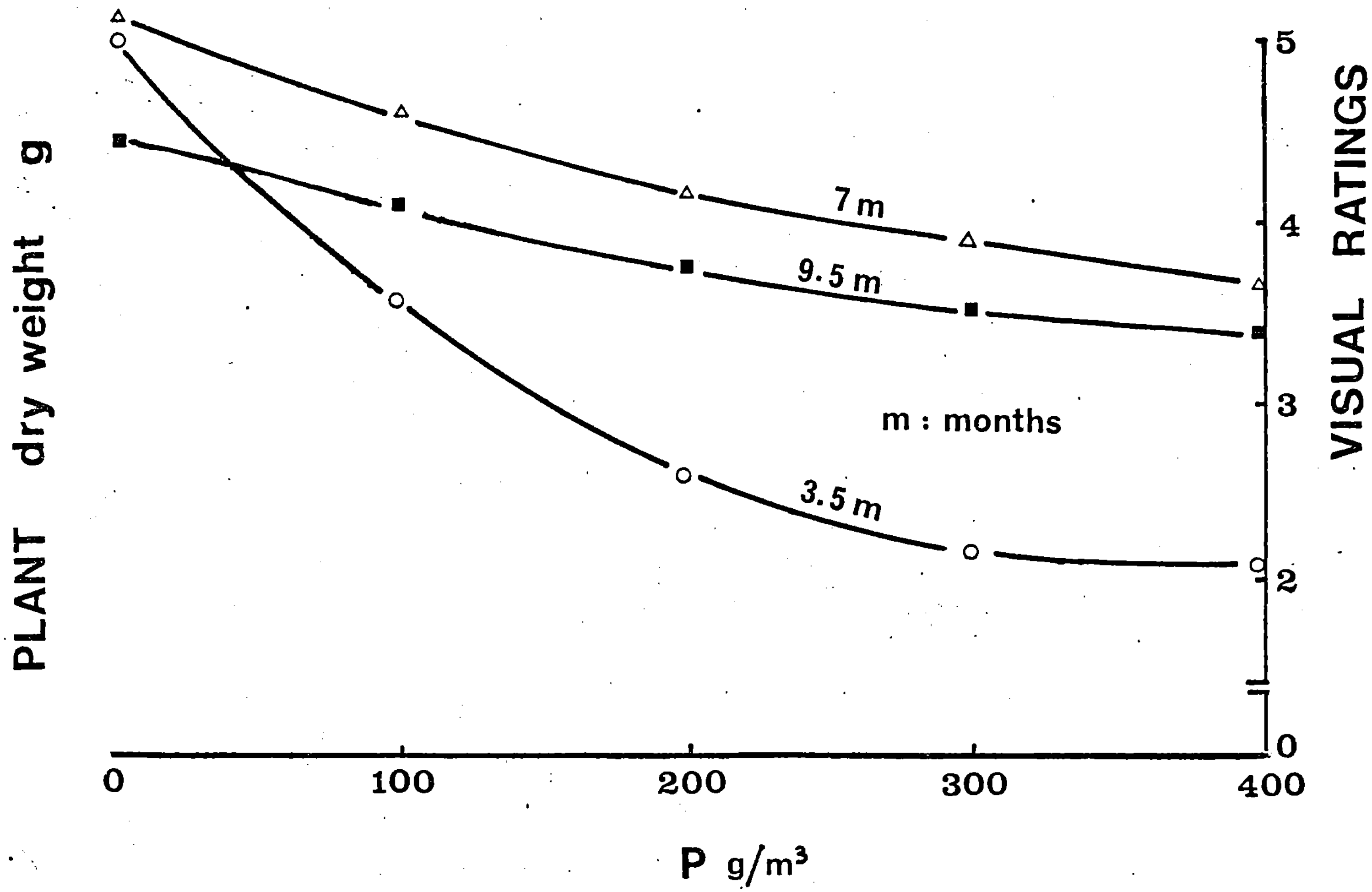

Fig. 5: Expt. B. The influence of phosphorus on foliage growth of *Grevillea rosmarinifolia*. Visual ratings and dry weight (g/plt.)

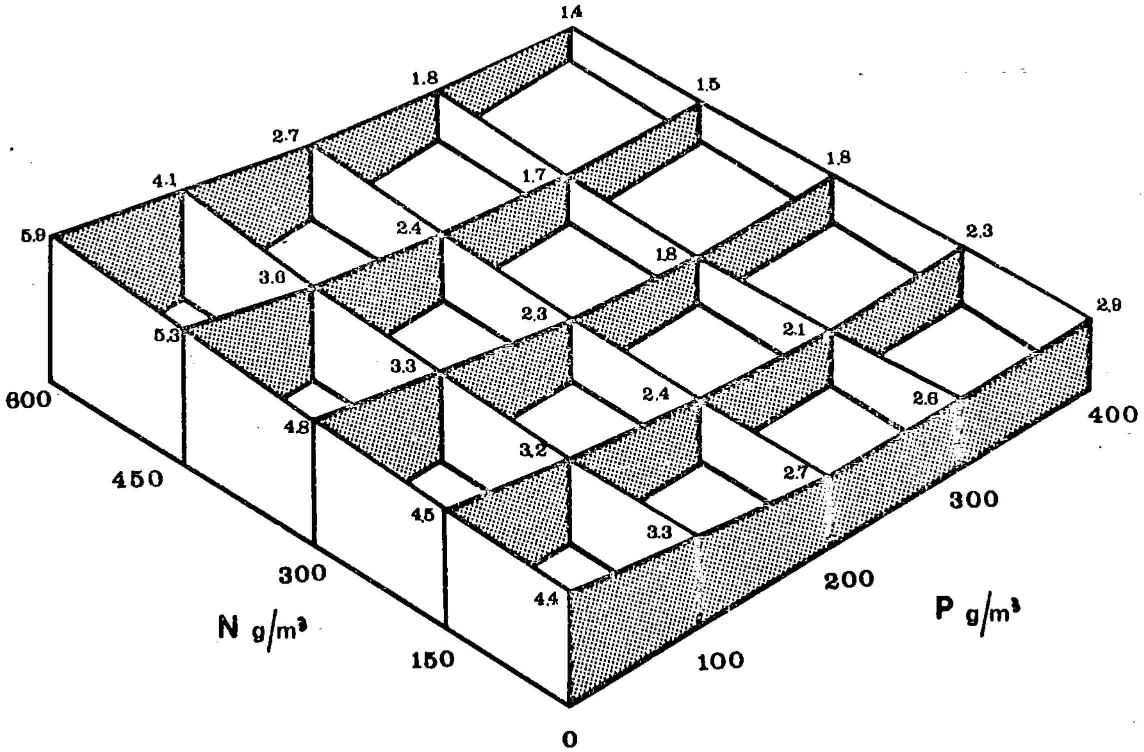

Fig 6: Expt. B. Interaction of N and P fertilisation on the foliage growth of *Grevillea rosmarinifolia*. Visual rating at 2 months.

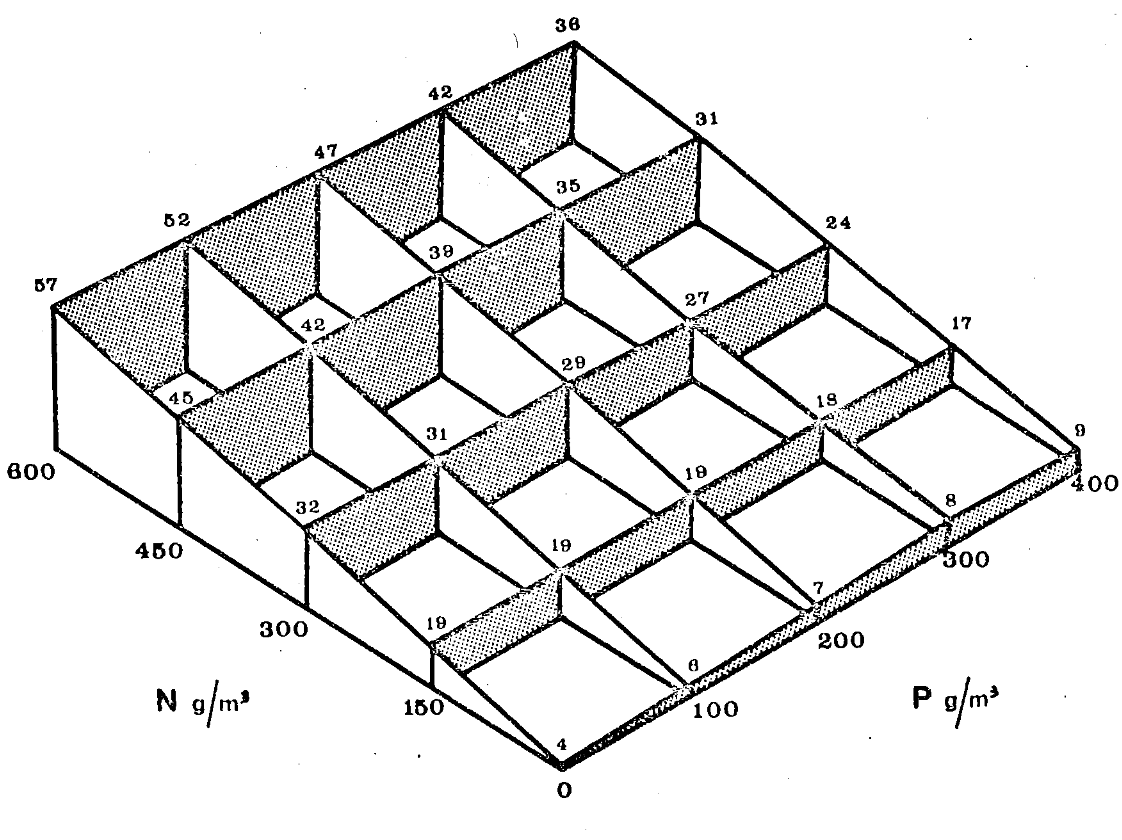

Fig 7: Expt. B. Interaction of N and P fertilisation on the foliage growth of *Grevillea rosmarinifolia*. Dry weight: g/plt.

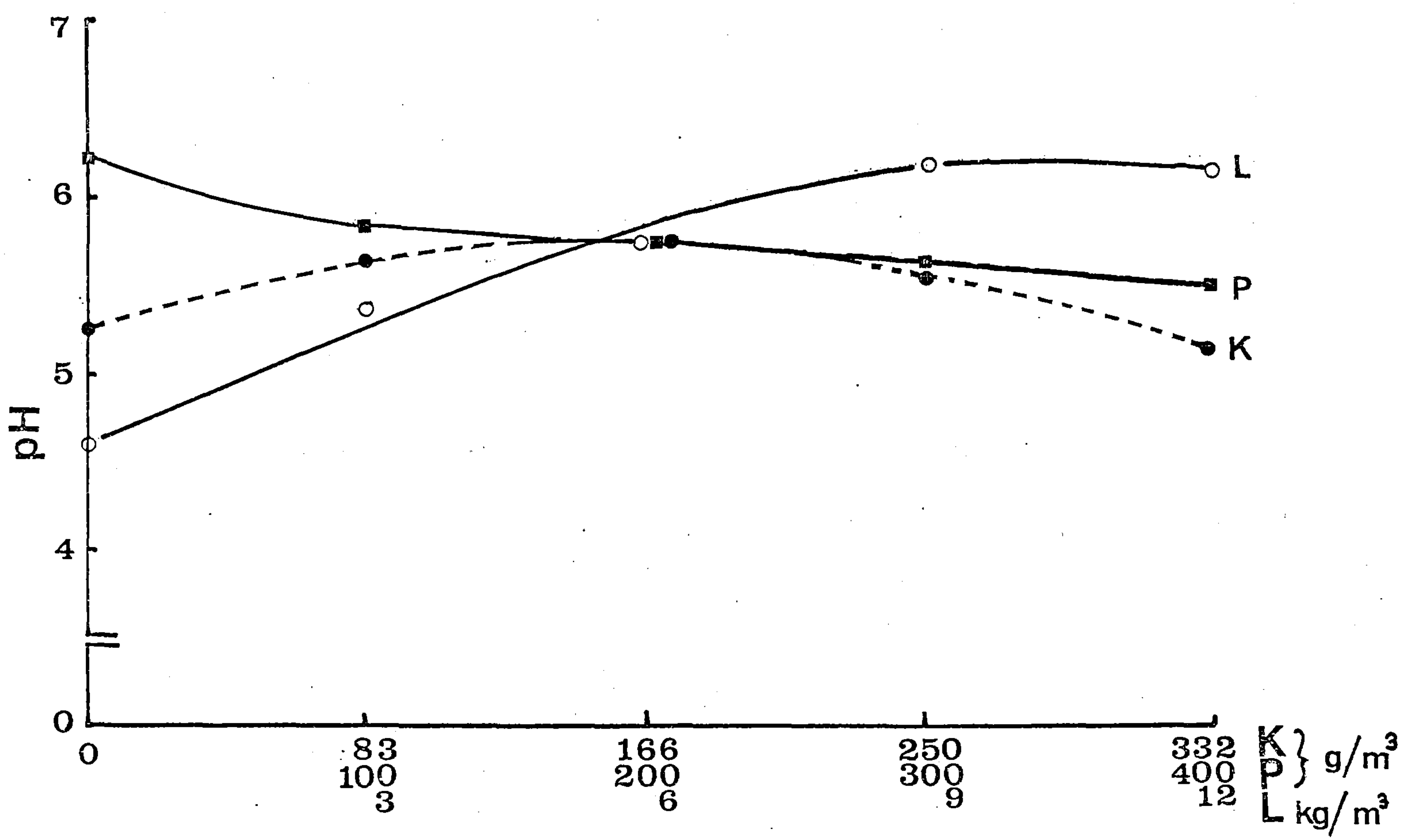

Fig. 8: Expt. B. The influence of P and K fertilisation and liming on the pH of P/P potting mix.

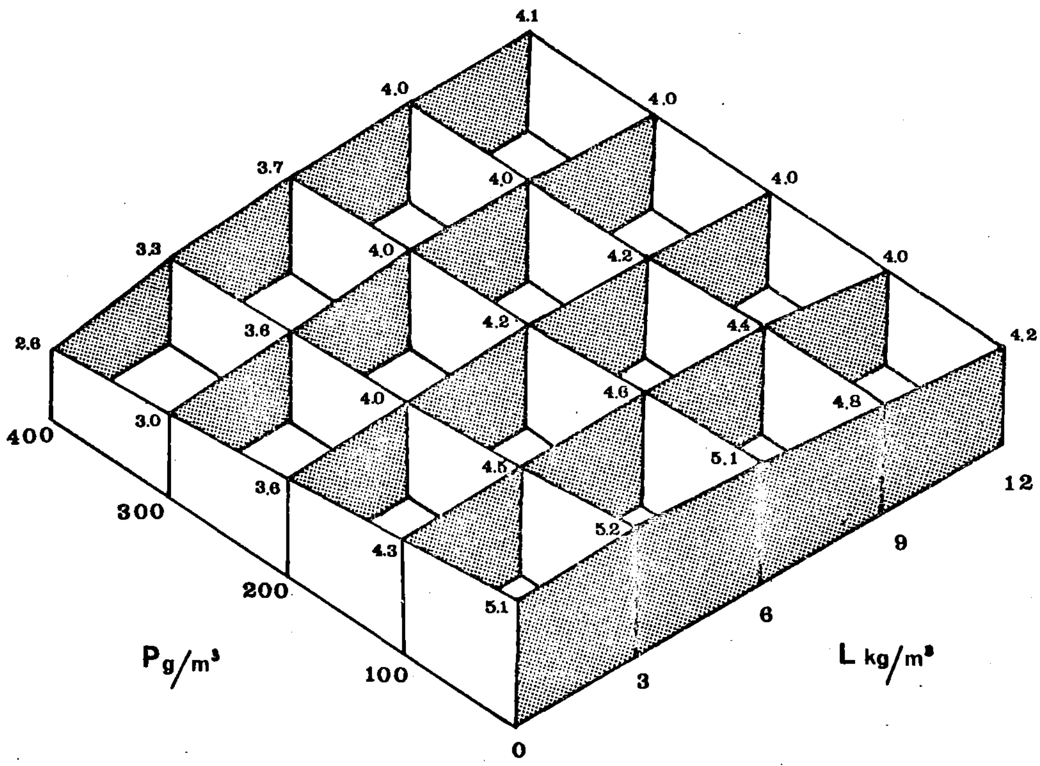

Fig 9: Expt. B. Interaction of P fertilisation and liming on the foliage growth of *Grevillea rosmarinifolia* visual rating at 7 months.

and dry weight response to K (Table 3) which only approached significance (P = 6% in both cases). Lime also influenced dry weight at the same level of significance and lime additions depressed growth (Table 3).

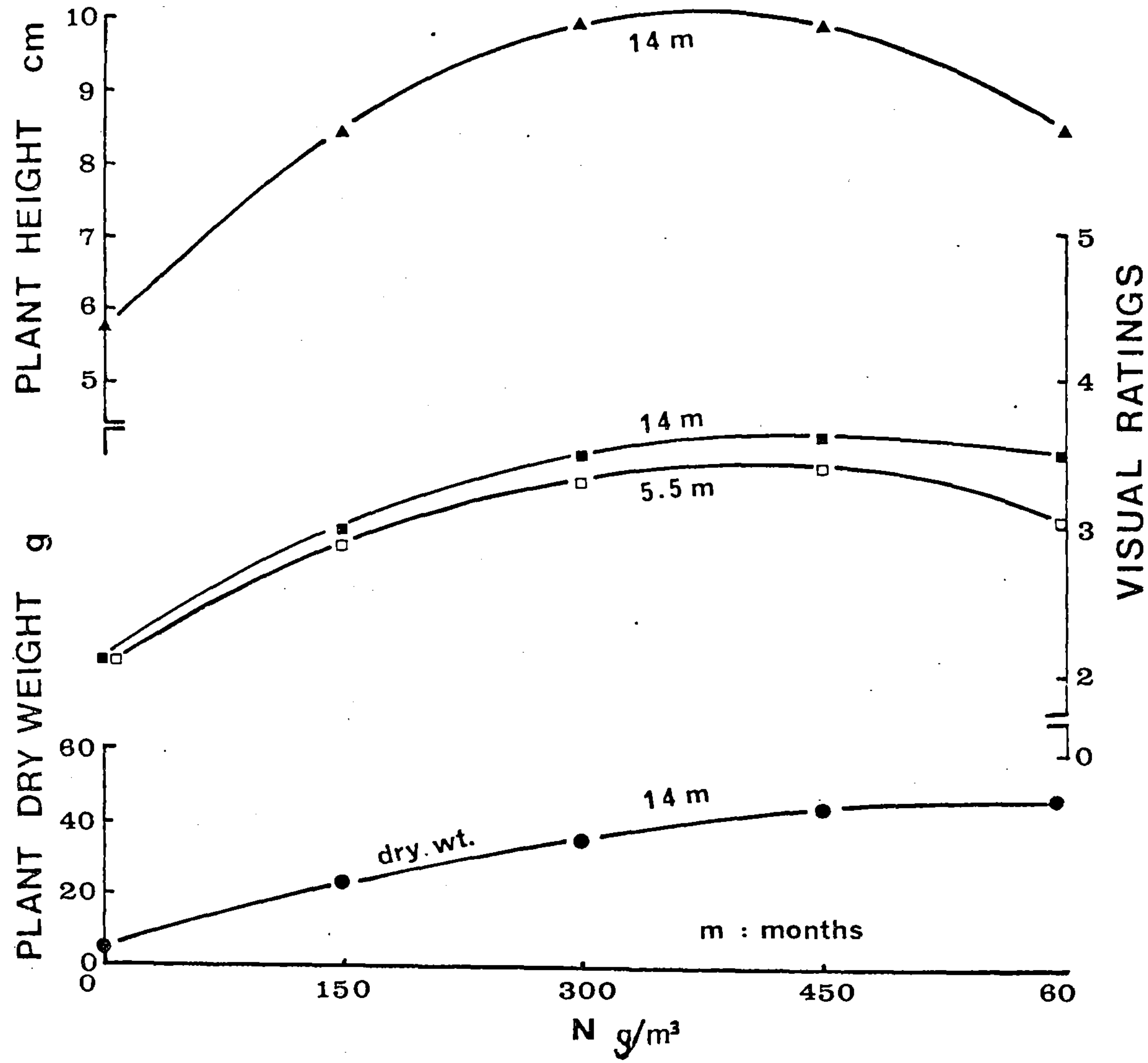

Fig. 10: Expt. C. The influence of nitrogen on foliage growth of *Hakea laurina*. Visual ratings, height and dry weight (g/plt.).

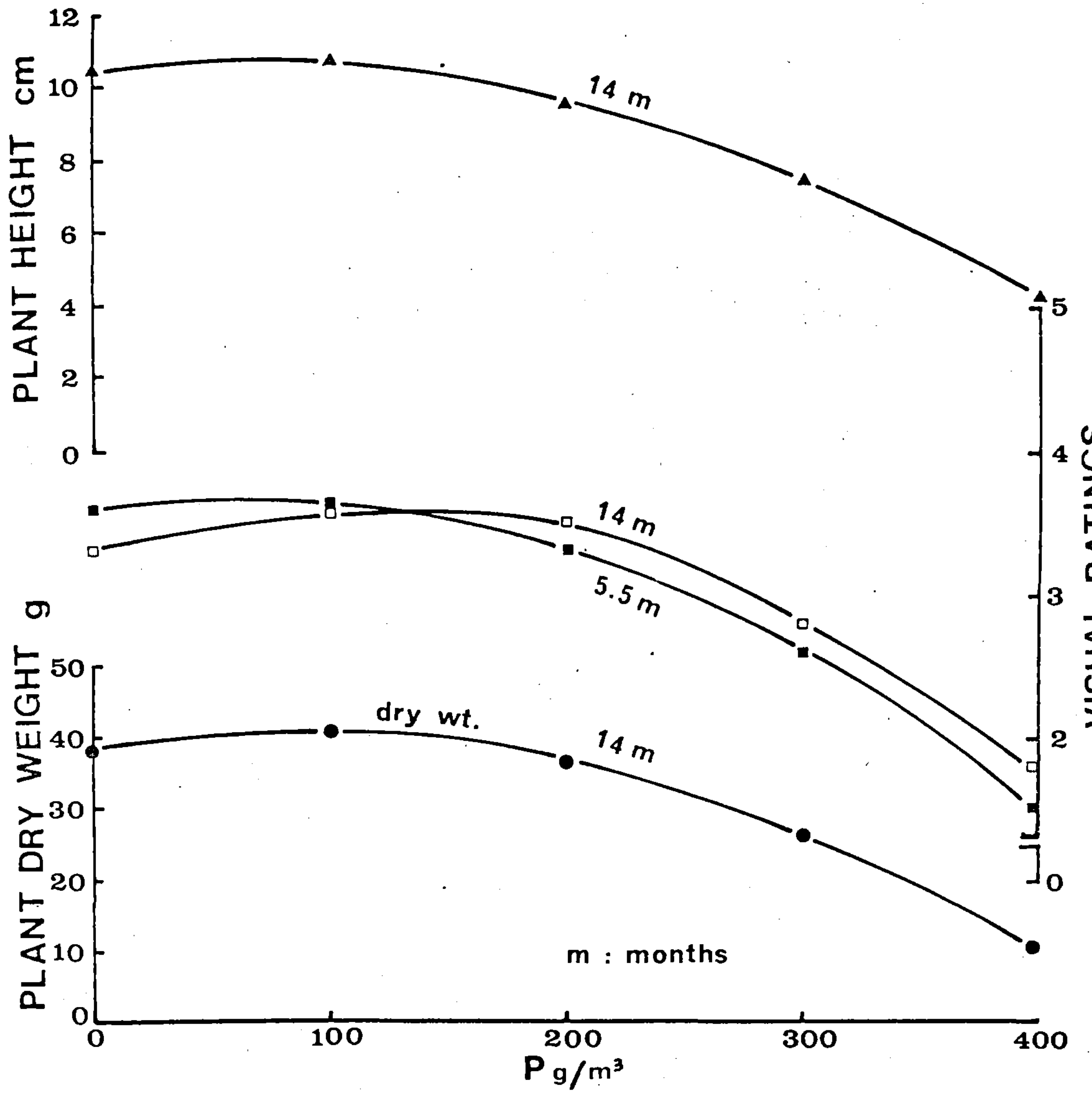

Fig. 11: Expt. C. The influence of phosphorus on foliage growth of *Hakea laurina*. Visual ratings, height and dry weight (g/plt.).

DISCUSSION

Callistemon citrinus

There are 25 species in the genus *Callistemon* and these are all native to Australia and New Caledonia (Prakash 1969). This is an adaptable genus and although all members prefer a moist sunny position, they will also grow successfully in dry positions in Australia (Brooks 1961) and react well to small amounts of organic fertilisers applied in autumn (Fairall 1970). *C. citrinus* definitely fits into the robust category and Harrison (1960) states that it is able to withstand hot, dry and poor soils in New Zealand while Brooks (1961) pointed out that hot, moist conditions on any soil were satisfactory for it in Australia.

Lamont (1973) has stated that the Myrtaceae are generally faster growing than proteaceous shrubs of the Australian heathlands and that the former are likely to be less tolerant of very infertile soils. Beadle (1966) pointed out that plants from more fertile conditions such as rainforest areas may not, or have not been able to compete in the heathlands more because of inability to cope with, or adapt, to low nutrient supplies than because of the low rainfall. He also noted that *Leptospermum squarrosum*, in the Myrtaceae, responded in a very similar way (leaf area v leaf number from base) to *Lambertia formosa* (Proteaceae) when supplied with high and low nutrient additions; although *Banksia ericifolia* (Proteaceae) was quite different. Higgs (1970) also found similarities between *Grevillea rosmarinifolia* and *Leptospermum scoparium* 'Lambethii' since both grew equally well with nil, half and full fertiliser rates when grown in a soil mix supplemented weekly with a mild liquid feed. One of the most significant aspects of the results reported here was the similarity between the nutrient responses of callistemon and the proteaceous shrubs, particularly *G. rosmarinifolia* and although callistemon showed a greater response to added nutrients at low N and P levels, the response to N and negative NP interaction showed a close resemblance in both plants. The conclusion is that these plants could be treated in a similar manner when grown in containers in the nursery and that differences in their native habitat are not significant in nursery container production. Rapid growth in response to added nutrients may however, have implications for the longevity of plants in the garden, especially in New Zealand on fertile, moist soils where Australian plants, adapted to harsh dry conditions, may be more short lived than those which prefer moister more fertile conditions. Australian heath species that respond to fertiliser additions have been shown to have a speeded up life cycle culminating in an early death (Heddle and Specht 1975).

Grevillea and *Hakea*

These two species responded similarly to added nutrients but it was noticeable that both in this study and in Chapter 4 *H. laurina* showed a greater sensitivity to added P than did *G. rosmarinifolia*. In both cases P toxicity was severe in the hakea while *G. rosmarinifolia* has consistently shown an ability to recover from serious P toxicity. *Hakea laurina* adapts readily to garden cultivation is a rapid growing plant, can tolerate light to rich soil (Fairall 1970, Brooks (1961), and consequently is the most popular *Hakea* spp. in cultivation. Grevilleas and hakeas often occur together naturally and are widely distributed on similar habitats (Lamont 1973). Hockings (1970) states that grevilleas are one of the more difficult genera of native Australian plants to cultivate and Higgs (1970) found *G. rosmarinifolia* intolerant of a high fertiliser regime, especially if planted too deeply. Despite these latter comments *G. rosmarinifolia* is clearly a robust species and in fact Brooks (1961) states that it can often be used where other plants do not survive and that it may become too large for its position in the garden, requiring trimming. Both *H. laurina* and *G. rosmarinifolia* are rapid growing cosmopolitan species but it may be concluded that the latter is the more P tolerant species possibly because of its greater resilience and adaptability.

Jeffrey (1964) has shown that many Proteaceae are calcifuges and, because they are adapted to make maximum growth at low Ca levels, they are unable to avoid excessive Ca uptake when grown in soils with high levels of Ca, resulting in toxicity. Lamont (1973) points out however that Australian heathland Proteaceae grow on a wide range of soils including laterite, granite, sandstone, sand-dunes or even limestone. He comments that these soils are often acid, as a consequence of their infertility, but that they may also be neutral or even alkaline. *G. rosmarinifolia* and *H. laurina* (also *Callistemon citrinus*) have been noted on limestone areas (Lindross 1977) and Fairall (1970) gives several species which tolerate alkaline conditions. Hockings (1970), however, when outlining the culture of grevilleas, stated that they prefer a soil of definite acid reaction and this primarily supports Lamonts' observation that both genera mostly grow in acid soils. The present study has indicated that hakea and callistemon prefer a pH of about 4.5 in a peat-sand mix without lime and that only *G. rosmarinifolia* showed a need for a rate of 3 kg/m^3 of lime, to raise the pH to approximately 5.5.

Proteaceous plants are prone to chlorosis particularly on calcareous soils in Australia and it may be necessary to add iron chelates (Lamont 1973). Higgs (1970) found that severe chlorosis occurred on *G. rosmarinifolia* grown in containers with full strength fertiliser containing 5 parts sand, 3 parts peat and 1 part sand. Similarly, Grundon (1972) noted that several container grown *Banksia* spp. and *H. gibbosa* showed chlorosis at high N levels while Specht (1963) noted P induced cholorosis on *Banksia* in the field. No chlorosis was noted on any of the 3 species reported here and it is possible that the former workers observed iron deficiency symptoms initiated by high P and/or NH_4-N levels coupled with poorly aerated media. Unpublished work at Lincoln College has shown that poor aeration in a soil medium can be a key factor in inducing iron chlorosis while plants in soilless media with high P or lime levels may appear completely healthy despite having lower native iron levels. Necrosis, leaf distortion and stunted growth have often been caused by P toxicity but at no stage in any of the experiments at Lincoln have high P levels been the apparent cause of chlorosis.

CHAPTER 7

NUTRITION OF CONTAINER GROWN

ERICA CARNEA L. 'SPRINGWOOD WHITE'

ABSTRACT

Plants of *Erica carnea* 'Springwood White' were grown in peat:sand (1:1, vv) and responded strongly to N while optimum growth occurred with 200g P/m^3 applied as a base dressing. Increasing lime rates depressed growth. High N fertilisation had more pronounced influence on foliar nutrient levels than other added nutrients. Results were consistent in 2 experiments run at separate times of the year.

INTRODUCTION

Previous chapters reported on nutritional studies involving proteaceous shrubs and some other species. This chapter deals with the study of the nutrition of a temperate shrub and includes two factorial experiments one of which is an incomplete block composite design.

Erica carnea 'Springwood White' was found to be sensitive to high fertiliser rates (Anon 1971) and is said to require low levels of feeding (Carter 1973) and acid conditions (Alvey 1955). Ericas are prone to chlorosis under unfavourable conditions (Alvey 1955, Anon 1971) and respond to high aeration in the rooting medium.

MATERIALS AND METHODS

Plant Species and Growing Conditions

Two experiments were carried out using 680 plants of *Erica carnea* L. 'Springwood White' as follows:

	No. of Treatments	Replicates (plts./treat)	Dates Bagged	Sidedressed	Lifted
Expt. A	13	25	24.12.72	-	24.10.73
Expt. B	30	12	8. 5.73	20.9.73	26. 6.74

All plants were raised from semi-ripe tip cuttings propagated under mist which were potted-up into tubes containing very low nutrient levels. Experiment A was rur in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Experiment B was run in a shadehouse covered with 50% polypropylene shadecloth (Sarlon). Hand watering was done in both trials when required.

Experimental Design, Media and Fertilisers

Experiment A was a 2^3 NPK factorial with 5 additional treatments using the same as those described in Chapters 1 for Experiment A (Table 1). Experiment B was an incomplete block composite factorial as described for the 3 experiments in Chapter 6 - levels and rates of fertiliser are given in Table 4. The medium used for both experiments was equal parts (1:1, vv) Dipton sphagnum peat and fine grade perlite. The physical and chemical characteristics of each medium was described by Goh and Haynes (1977a) and Morrison *et al.* (1960), respectively.

A base dressing of 0.25 kg/m^3 Osmocote 18/2.6/10 was used for all treatments in Experiment A but not Experiment B. All additional rates of N, P and K, and all of these nutrients for Experiment B, were supplied from Osmocote (26% N), Superphosphate (9% P) and sulphate of potash

(39 % K) respectively. All treatments in Experiment A included a base dressing of 4.5 kg/m^3 dolomite plus 1.5 kg/m^3 agricultural lime (Ca CO_3). Lime rates in Experiment B were varied but still kept in the same 3:1 ratio as in Experiment A (Table 4). Media in both experiments received the same base dressing of trace element fertilisers: 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB 5 (2½ l) 'Plantabags' just prior to potting. The nitrogen, supplied from Osmocote (26% N) in Experiment B, was applied in two equal amounts. A side-dressing was mixed into the top 2cm of the potting medium at 4½ months after the basal application at laying down. This was done to minimise the toxic effects of high N levels supplied from a short to medium term fertiliser.

Media and Foliar Analyses

Media samples were taken on 12.7.74 and pH levels were measured with a glass electrode using a 1:2·5 soil-water ratio. One replicate per treatment was randomly selected from Experiment B and the pH data statistically analysed using the same computer programme as that used for other data for Experiment B (see Data Collection and Analysis). The influence of the treatments on pH is summarised on Figure 4 and the C.V. (%) was 2 and R^2 (%) = 10 for trial variance and closeness of fit for regression analyses. There were no significant interactions between nutrients and liming for their influence on acidity of the medium.

Five samples of foliage were randomly selected from the factorial treatments in Experiment A and sent to Ruakura Research Station (Ministry of Agriculture and Fisheries) where they were ground and levels of N, P, K, Mg, Ca and Na obtained as outlined in Chapter 1.

Data Collection and Analysis

Visual ratings of foliage were carried out, using the grading system outlined in Chapter 1, on 13.5.73 and 19.7.73 for Experiment A and on 10.12.73 for Experiment B.

Foliar analyses, visual ratings and dry weights were statistically examined for Experiment A using Teddybear (now Crypto/teddybear) computer programme for analysis of variance and F test. Data for Experiment B utilised computer programme 'Boxhu'.

RESULTS AND DISCUSSION

The main effects for Experiment A and B are given in Tables 1 and 5 respectively, interactions in Table 2 and the constants and coefficients of response surfaces for Experiment B are shown in Table 3.

Nitrogen had a strong positive influence on foliage growth in both trials. Added P quite strongly enhanced this effect in the early stages of Experiment A (Table 2) but a positive NP interaction was not apparent in subsequent dry weights nor in Experiment B. Foliar ratings at 7 months for Experiment B demonstrated a quadratic response to N as shown in Figure 1. In contrast N produced a highly significant linear response in dry weight and showed no toxicity even at the highest rate. This was probably accentuated by the fact that the N sidedressing was applied after 4½ months and the trial was run for over a year but without the use of long term Osmocote.

The yield data for plants in additional treatments given in Table 1 provide further information on extreme nutrient levels. Results from these simple treatments allow better interpretation of the NPK nutrition of erica when they are considered with the factorial ones. Plants in the nil fertiliser treatment were of only medium to fair quality at 6 months and were poor at 8 months. Very high levels of N and especially NPK were

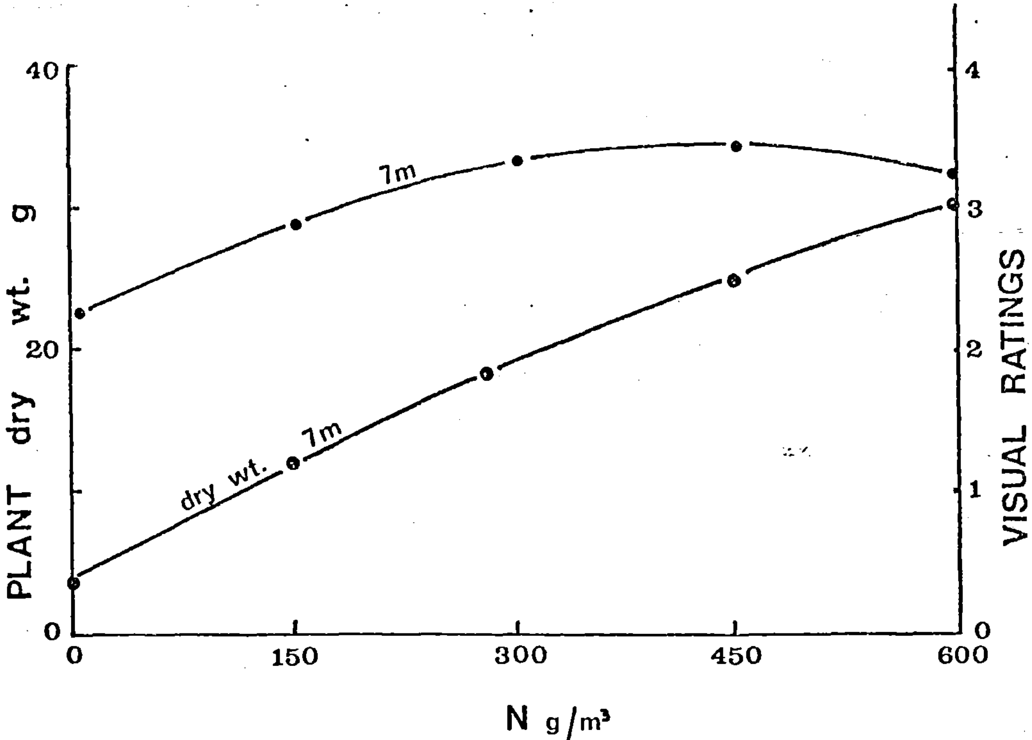

Fig. 1: Expt. B. The influence of N fertilisation on the foliage growth of *Erica carnea* 'Springwood White' (m = months for visual ratings, dry wt. - g/plt.)

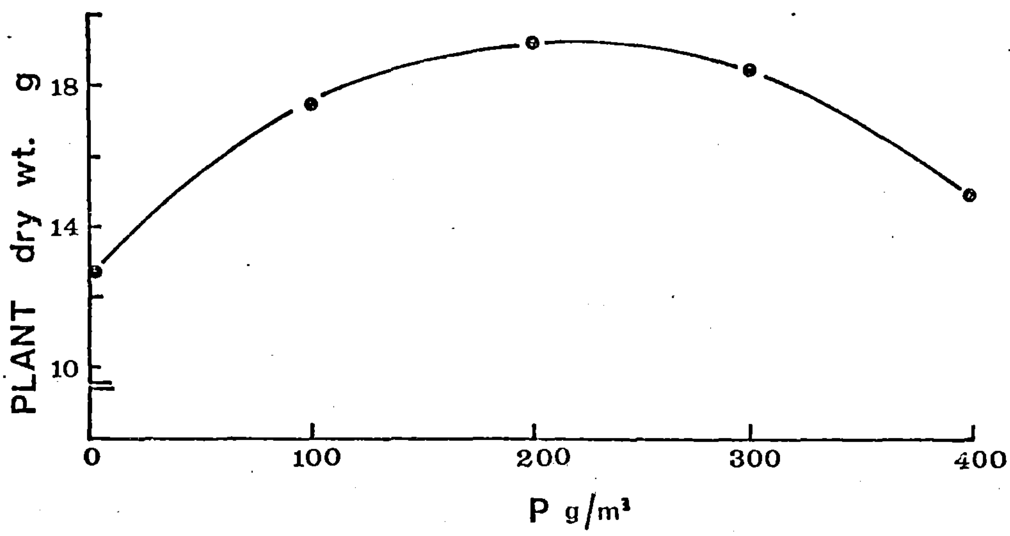

Fig. 2: Expt. B. The influence of P fertilisation on foliage growth.

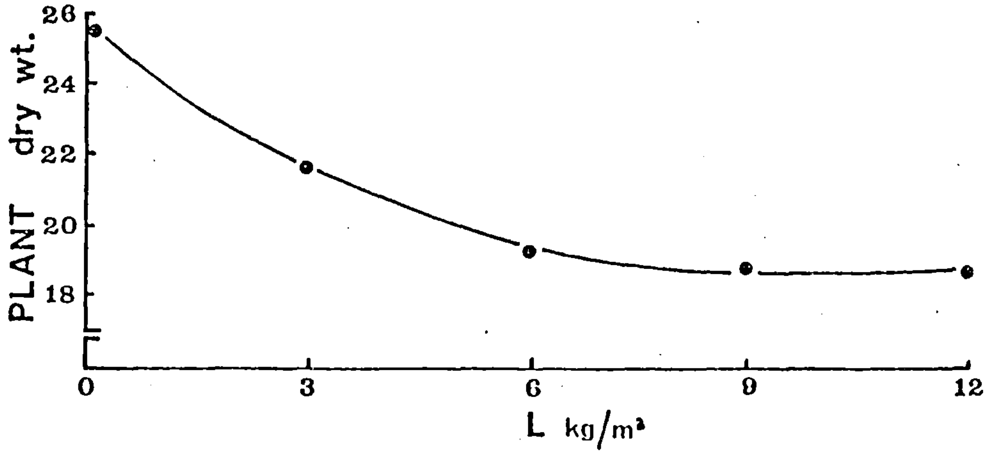

Fig 3: Expt. B. The influence of lime rates on foliage growth.

obviously toxic at 6 months and subsequently gave rise to poor grade plants. The treatment, with all 3 nutrients at very high levels, proved severely toxic probably due to the combined effect of high NH_4 levels with P and high soluble salts as indicated by media analyse in Chapter 1. The treatment with very high P and medium high N (2) appeared satisfactory at 6 and 8 months but at harvest the level of P was clearly in the toxic region and dry weights were similar to those in the high N and K treatments. Experiment B substantiates this observation on P toxicity. Osmocote 18/2.6/10, the commercial 8-9 month fertiliser, was used in additional treatment 6. This treatment allows some estimation of the possible levels that can be recommended for commercial potting media rather than relying on extrapolation from the use of Osmocote (26% N) which is not used commercially. This was obviously a successful treatment and plants were superior to those in the other 5 additional treatments although not at 6 or 8 months. Recommendations could reasonably be made concerning the use of Osmocote 18/2.6/10 in potting media since the additional treatment with this fertiliser correlated reasonably closely with the corresponding factorial treatments involving Osmocote (26% N).

No NP interactions occurred in Experiment B and there was a quadratic response to P (Figure 2) which indicated that the optimum rate was about 300 P/m^3. This was the same rate as that used at the high P level in Experiment A but which produced no response to P in the dry weights.

The influence of N and P fertilisation and lime rate on acidity of the medium (Experiment B) is shown in Figure 4. Lime rate had the most pronounced influence and a typical sigmoid pH response curve was obtained. Medium and high N levels from Osmocote (26% N) depressed the pH while high P levels from superphosphate had the opposite effect. The pH curves were similar to those shown in Table 8, Chapter 6. Responses to lime were also only significant for foliar dry weights and not ratings in the composite trial. In this case lime had a negative effect with greatest yields at the nil rate and increasing lime levels depressing foliage growth (Figure 3). This was to be expected as erica is a well known calcifuge and in this experiment preferred a pH of below 5. Growth depression with increasing lime rates was not due to inadequate iron supplies since iron chelate had provided adequate amounts of iron. Growth was also depressed by high P rates and it was noticeable that these raised the pH (Figure 4) although no conclusions are feasible on how these factors influenced growth.

No chlorosis occurred on plants in the two trials despite the high lime rates and low N treatments and therefore the stated need for low pH's to avoid chlorosis (Alvey, 1955), does not hold here. Alvey (1955) had found that less chlorosis occurred in loamless media rather than soil mixes while Gray (1971) had proclaimed the advantages of improving the physical properties of soil media for improved growth for ericaceous plants. The chlorosis reported on by these 2 workers was probably due to poorly aerated media which under moderately high pH's is likely to initiate iron deficiency. Iron induced chlorosis is therefore not a problem even at high lime rates if the physical properties of the mix, particularly aeration, are satisfactory. Chlorosis and die back in erica has also been reported in other work (Anon 1971) under excessive fertiliser levels in loamless, rather than soil mixes, in the same variety as the one reported here. No explanation for this anomaly can be offered even though lime and other elements were used at high rates in the work reported here.

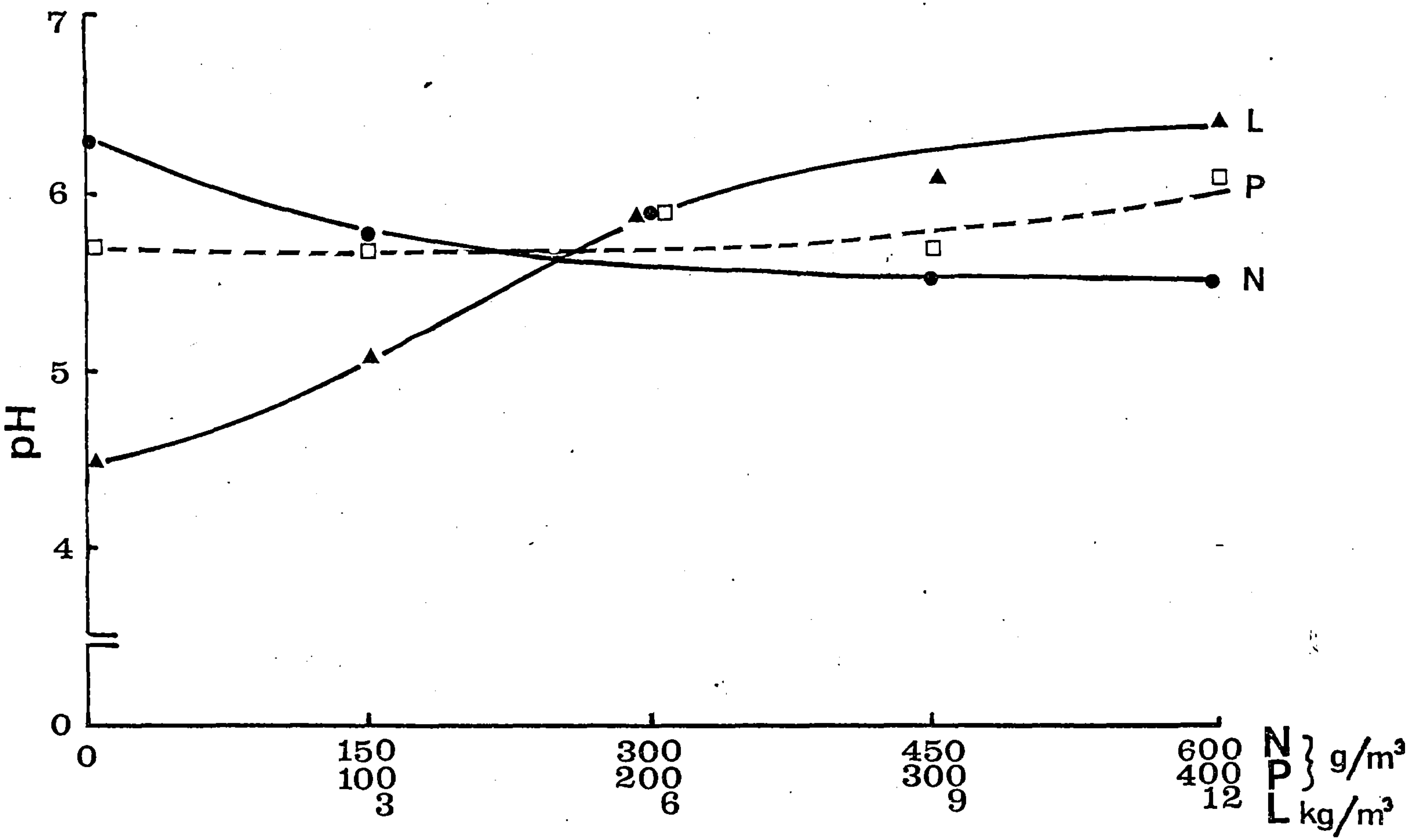

Fig 4: Expt. B. The influence of N and P fertilisation and liming on the pH of P/P potting mix.

Foliar Analyses

Foliar analyses were conducted only on plants in Experiment A and the main effects of treatments on 6 foliar nutrients are given in Table 6. Nitrogen feeding produced a highly significant influence on all 6 nutrients. It strongly promoted foliar N and also Na levels especially when added P was also high (Table 7) but it depressed the foliar levels of P, K, Mg and Ca. Levels of P were halved at N_1 compared with N_0 and the reduction of foliar K was also strong.

High levels of P in the medium strongly promoted foliar P levels providing N was added at a low rate (Table 7). Levels of K in the foliage were influenced by a similar inhibition by N fertilisation, whereby uptake stimulated by P could only occurr at N_0 (Table 7). Foliar Ca was enhanced by added P and there was no indication of depressed levels of other nutrients in the tops when added P was at high levels (Table 7). Ticknor (1976) could find no indication of very high foliar Ca levels in rhododendrons, which are also calcifuges.

High K fertilisation initiated high K levels in the tops particularly when added N and P were low (Table 7). Additions of this element had no promotive influence on any of the other nutrients and foliar Mg was quite strongly reduced at N_1 K_1 (Table 7).

CONCLUSIONS

Early work indicated that ericas are minerally sensitive plants which are subject to chlorosis. The experiments reported here indicate that they can be grown successfully in a loamless medium with quite high rates of N (80-100g N/m^3/month) coupled with medium base dressings of P (up to 200g P/m^3). A peat-sand (1:1, vv) medium proved very satisfactory and no chlorosis occurred even with 12 kg/m^3 of lime added although the presence of iron chelate may have assisted in preventing yellowing; it is felt that sufficient aeration in the medium is probably more important than soil pH. Increasing lime levels correlated negatively with foliage growth while N fertilisation was strongly promotive, mediated by enhanced foliar N levels which were coupled with depressed P, K, Mg and Ca uptake.

CHAPTER 8

NUTRITION OF CONTAINER GROWN <u>FATSIA JAPONICA</u> DECNE AND PLANCH, <u>FICUS ELASTICA</u> ROXB., <u>DIANTHUS CHINENSIS</u> (L.) NEES 'DWARF FRAGRANCE', AND <u>TAGETES PATULA</u> L. 'SPARKY'.

ABSTRACT

The nutritional requirements of 2 pot plants and 2 bedding plants were studied using container grown plants in peat:perlite or peat:sand (both 1:1, vv). They were supplied, in factorial combinations, with various levels of N, P and K derived primarily from Osmocote (26% N), superphosphate and sulphate of potash. *Fatsia japonica* responded only moderately to N at 450 g/m^3 while foliage growth was not promoted by high P or K levels. *Ficus elastica* responded well to N and P and there were strong positive NP and NK interactions. These and alternative fertilisers indicated that 75g N/m^3 per month was satisfactory although the relatively low foliar N levels which resulted indicated that this may be conservative. *Dianthus chinensis* 'Dwarf Fragrance' responded very strongly to added N and there were positive NK and NP interactions. *Tagetes patula* 'Sparky' grew most strongly with high N, NK or with high K, or PK. High N fertilisation promoted high foliar N, P and Mg and the foliage composition agreed closely with the findings of other workers. Optimum levels for the 2 bedding plants in g/m^3 appeared to be 450 N (85g N/m^3/month), 150 P and 300 K with 6kg/m^3 of a dolomite:carbonate of lime mixture.

INTRODUCTION

Bedding plants, other seedlings and pot plants are often grown in the same nursery by New Zealand nurserymen. Information on the comparative nutrition of a range of commonly grown species should therefore be useful so that growers can 'design' media to meet the nutritional requirements of certain types of plants.

Penningsfeld (1972) studied the macro and micro nutrient requirements of 3 pot plant species and much work has been carried out in Florida on foliage pot plants by Conover and Poole (1977 and earlier). There has been little work on the nutrition of *Fatsia japonica* but other members of the Araliaceae such as *Nothopanax guilfoylei* (Poole *et al* 1968) and *Hedera* (Conover and Poole 1977, Seager 1973) have received some attention. There has been more work on *Ficus* spp than *Fatsia*, including the response of *F. benjamina* to Osmocote additions (Conover and Poole 1977) and *F. elastica* to Magamp (Seager 1973).

Dight (1977) reported on a four year research programme on the nutritional requirements of a range of bedding plants and emphasised the difficulties of commerically producing a range of plants with such differing cultural requirements. Tsurushima and Date (1971, 1976) also looked at the fertilisation of a wide range of bedding plants. Wille (1968) has attempted to devise an optimum fertilisation formula for young plants in peat.

The objective of the work reported in this chapter was to examine the nutrition of 2 pot plants and 2 bedding plants using similar media, fertilisers and growing conditions.

MATERIALS AND METHODS

Plant Species and Growing Conditions

Five experiments were carried out with 2 bedding plants and 2 pot plants. The plants used, laying-down and harvest dates, and the number of replicates are given in Table 1. *Ficus elastica* were the only vegetatively propagated plants and were raised from leaf bud cuttings under mist. The *Fatsia japonica* seedlings and *F. elastica* rooted cuttings were potted-up into tubes containing a medium with very low nutrient levels, following initial propagation. The other seedlings were pricked out directly into the treatment media from seed boxes. All experiments were run in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Hand watering was done when required and no additional fertiliser applications were made following initial base dressings at laying down.

Experimental Design

Experiments A, B, C and D were factorial experiments with a 2^3 or 3^3 NPK (randomised block) design as shown in Table 2. Additional treatments were used in Experiment A, Chapter 2, and were laid out alongside the factorial treatments within the same randomised blocks. Additional treatments were not included in the factorial analysis and Duncan's test was used instead. Experiment E used a central composite rotatable multifactor design (Box and Hunter, 1957), because of the possibility of obtaining a large amount of information from a relatively small number of plots. It involved N, P, K and lime with 30 plots arranged in 3 blocks of 10 plots each so that quadratic response curves could be calculated for each factor and for the derivation of two factor interactions. Each factor was present at five levels which were coded as -2, -1, 0, 1 and 2 (Table 6).

Media and Fertilisers

The medium for Experiments B and D was equal parts (1:1, vv) Mataura sphagnum peat and coarse manufactured sand (60% of particles 1.00 - 3.57mm diameter). The physical and chemical characteristics of these two media was described by Goh and Haynes (1977 a). In experiments C and E the sand was replaced by fine grade perlite (properties given by Morrison *et al.* 1960). The levels of N, P and K used for Experiments A, B, C and D are given in Table 2 and were based on 0.25 kg/m^3 of Osmocote 18/2.6/10 with additional levels of N, P and K supplied from Osmocote 26% N, superphosphate (9% P) and sulphate of potash (39% K) respectively. In the composite factorial (Experiment E) all P and K was derived from the latter 2 fertilisers and N solely from Osmocote 26% N applied in the base dressing.

Additional treatments for Experiments A, B and D were based on peat/sand (1:1, vv) instead of peat/perlite or alternative types or levels of slow release fertiliser was used: 8 - 9 month Osmocote (18/2.6/10) or Floranid Nitrophoska (10/2/7) or Uramite (38% N) with additional P and K rates supplied as in the factorial treatments. The additional treatments, NPK rates, media and key to fertiliser sources are given in Table 5. Those treatments labelled 'FRO' (Fast Release Osmocote) were based on the same fertilisers as the factorial treatments.

Lime application was based on 3 parts dolomitic to 1 part (W W) agricultural lime ($CaCO_3$) and was applied at 5 levels in the composite experiment (Table 9) and at 6 kg/m^3 in the other 4 experiments. Sporumix A trace element mix and 'Sequestrene' (NaFe) iron chelate were used in these 5 experiments at 150 and 75 g/m^3 respectively. The plants in Experiment A and B were grown in PB 5 (2½l) 'Plantabags', Experiment C in 8cm Plixie pots and Experiments D and E in PB 3 (1½l) 'Plantabags' just prior to potting.

Data Collection and Analysis

Height measurements were made on the *Ficus elastica* plants (Experiment B) during growth (27.5.75 and 1.10.75). On completion of all experiments the plants were cut-off just above the medium and the foliage oven dried. All data from Experiments A, B, C and D was statistically examined using Teddybear (now Crypto/teddybear) computer programme for analysis of variance and F test. Data from the 4 factor central composite design (Experiment E) was processed by the computer programme 'Boxhu' available from the Lincoln College Computer Centre.

RESULTS AND DISCUSSION

Fatsia japonica

This house plant was grown for 9 months and in that time failed to respond to P and K, and only showed a moderate foliar dry weight response to N (Table 2). There were no interactions. It appeared to be quite tolerant of very low levels of N, P and K and showed no deficiency symptoms, nor obviously depressed growth in any treatments.

The results obtained with additional treatments (Table 5) support those from the factorial experiment in that they also demonstrate that this plant is not very responsive to added nutrients. There was no difference between 3 levels of added slow release Osmocote (additional treatments 1, 2 and 3). In fact Treatment 1 (Table 5) gave the highest mean dry weight for all factorial and additional treatments however this is not conclusive since there was no combined statistical analysis of factorial and additional treatments. Nevertheless this showed that 450:300:250 NPK, supplying only 53g N/m^3/month from 8 - 9 months Osmocote was satisfactory and not inferior to higher N levels.

Treatment 1 was superior to Treatment 4, P/S plus Osmocote 26% N at 225/150/125, which suggests that the N level in the latter was too low. This conclusion is a tentative one however because different media were used in these 2 treatments.

Fatsia is in the ivy family (Araliaceae) and one would expect that if it is similar to hedera then it would be relatively tolerant to infertile conditions. Seager (1973) showed that *Hedera canariensis* 'Mugo' was less responsive to Magamp (7/17/5) than *Ficus elastica* 'Decora' and the optimum rate for the two species was 5 g/l and 10 g/l respectively. He also noted that supplementary NK liquid - fertilisation was less beneficial to hedera than ficus and stated that it suggested a lower fertiliser requirement. Poole *et al.* grew another araliad, *Nothopanax guilfoylei*, in various media and with two levels of fertiliser applied monthly. The grade and growth of plants topdressed with 800:352:664 were both greater then in 400:176:332 NPK. However Rochford & Gorer (1961) state that all Araliaceae will grow satisfactorily in JIP (JIP 2 or 3 for ficus) or a loam and manure mix supplemented with superphosphate. This recommendation also supports the findings reported here, that members of the Araliaceae such as fatsia can be grown satisfactorily in moderate levels of N and low to medium levels of other nutrients. Seager (1973) reported on work with crotonylid-enediurea which showed that this ureaformaldehyde type material was a satisfactory N supply for hedera for up to six months.

Ficus elastica

This commonly grown pot plant was grown for 12 months and was much more responsive to added fertilisers than fatsia which is in agreement with Seager's (1973) observation on ficus and hedera as already discussed. Plants given high N levels were over 60% taller and had double the dry weight of those at the very low N level. These effects were further enhanced by added phosphate with a particularly strong positive NP interaction (Table 3). Potassium additions appeared to have little influence on plant height, nor did they affect dry weights at low N levels (Table 3) but the response to N at 450g N/m^3 was strongly promoted by high levels of K. Table 3 also gives the 3 factor interaction which shows that N, P and K can all be limiting and that when all three are at high levels foliage dry weights are maximised. Seager (1973) found Magamp satisfactory for ficus. This is noteworthy since this fertiliser is high in P (17%) which is released very rapidly at medium temperatures (Cochrane and Matkin 1967). Ficus seems to be a plant that is unusually responsive to P fertilisation.

It was noticeable that of all the additional treatments, treatment 6 (Table 5) produced plants with the greatest height at 6½ and 11 months and greatest final dry weight. These, however, were not significantly greater than in the other additional treatments except those where Floranid Nitrophoska was the fertiliser source. Floranid was toxic at the very high rate (NPK, 900:300:360) which is equivalent to 257g N/m^3/month. The same rate from 3 - 4 month Osmocote (Treatment 1) was quite satisfactory and this may be due to the fact that this Osmocote is relatively slow releasing initially (unpublished results) in contrast to Floranid which is released faster over the first 3½ months. Half the application rate of Floranid (Treatment 4) was inferior to the low application rate of Uramite (Treatment 6) and this may support this explanation since a rapid release of Floranid at the low rate would have accentuated deficiency problems at the end of the experiment. Growth of plants in Treatment 6 with Uramite, supplying an estimated 75g N/m^3 month, indicates that this combination of nutrients is close to the optimum N rate. The mean dry weight for this Uramite treatment was 91g/plant while the same foliar dry matter yield was obtained in the factorial part of the experiment (Table 3) with equal total nutrients and was the best combination of NPK there.

Rochford & Gorer (1961) stated that ficus requires JIP 2 or 3, (JIP 1 was recommended for the plants in the Araliaceae) which would provide between 82 and 122g N/m^3/month (Thomas and Spurway 1975) for the first 2 months and a slightly lower rate for the following 2 months. Conover and Poole (1977) found that *Ficus benjamina* supplied with increasing Osmocote (14/6/12), from 4 to 16g per 20cm diameter pot each 3 months, had increased foliage colour and grade but there was no effect on height or stem diameter after 9 months. Both these references support the view that rubber plants respond well to added nutrients.

No examples of strong foliar uptake occurred with *Ficus* and interactions between added nutrients appeared to have little significance (Table 6). High N fertilisation raised the foliar levels of N and Mg but reduced P, K and Na uptake. Additions of high levels of P to the medium raised the foliar levels of P, Ca and Na and no depression of uptake of any nutrient was apparent. High K fertilisation increased foliar K but was antagonistic to Mg uptake.

Poole *et al.* (1976) stated that the chemical composition of good quality *Ficus elastica* plants should be:- N: 1.3 - 1.6g% (of dry weight), P: 0.1 - 0.2g%, K: 0.6 - 1.0g% Mg, 0.2 - 0.4g% Ca: and 0.3 - 0.5g%. These figures are similar to the ones reported here with the exception of N which is 0.7g% less and Ca which is about 1g% higher. This may indicate that N fertilisation with Osmocote 26% N was not really adequate but on the other hand high N rates in the additional treatments did not stimulate growth significantly above that in the lowest N rates (Table 5). This, however, is inconclusive since the additional treatments, where high N rates were used, do not substantiate this hypothesis. The high Ca and Mg levels compared to Poole *et al's* (1976) recommendations are probably brought about by the lime rate of 6 kg/m^3 of which 75% was dolomite, a $MgCO_3$ material. These workers recommended foliar N and N:Mg ratios of 3.8 and 4.8 in ficus respectively (1.8 for N:K) however the ratios in this work reported here were approximately 0.3 and 1 which is well below that suggested for quality pot plants. They briefly discussed 'unusual' ratios and did not comment on their implications other than to suggest that future studies should be made to determine whether the recommended ratio is necessary for optimum growth. Conover and Poole (1977) found that increasing shade levels on *Ficus benjamina* strongly increased the foliar N:Ca ratio and that the ratio varied from 0.3 to 0.6 as shading was increased from 0 to 80%. Shading in the experiment reported here was less than 50% and this may help explain the very low N:Ca ratio plus the fact that Conover and Poole used dolomite at 4.2 kg/m^3 thus supplying plenty of available Mg and Ca.

Dianthus chinensis 'Dwarf Fragrance'

This seedling was grown for 3 months and responded very strongly to N while there was very poor growth in media with very low N levels (Table 2). High potassium had little effect when coupled with 45g N/m^3 but as the N rate increased there was an increasingly strong positive interaction between these two nutrients, as shown by the two factor and three factor tables (Table 4). The three factor interaction table also shows that the middle rate of phosphorus (150g P/m^3) is about optimal when combined with high levels of N and K. No additional treatments were used with this experiment.

Tagetes patula 'Sparky'

The marigolds responded very strongly to nitrogen in both experiments (Table 2, 8 and 10) with dry weights of plants grown at the highest level of N 3 to 4 times greater than that of plants in the lowest level. The quadratic N response is shown in Figure 1. The data in Experiment E had less variability than in the second with a coefficient of variation of 44% (Table 2) as against 78% (Table 8) in the latter and the levels of significance were generally higher in experiment D than in the composite trial (Experiment E). In the latter there were two factors approaching significance and no interactions. Added P mildly promoted foliage growth in Experiment D (Table 2) although this was much stronger in the presence of high K (Table 4). The optimum P level for Experiment E (Table 9 and 10) was about 150g P/m^3 (equivalent to 1.75 kg superphosphate per m^3) although this factor was only approaching significance (p=6%). Potassium strongly promoted foliage growth in the presence of high N in the simple factorial (Table 4) while in the composite (Experiment E) this interaction was not significant (Table 8). The K main effect was not significant in Experiment E (Table 8). Lime stimulated growth and the optimum appeared to be at 6 kg/m^3 (Table 10). This is also shown in Figure 1 where the

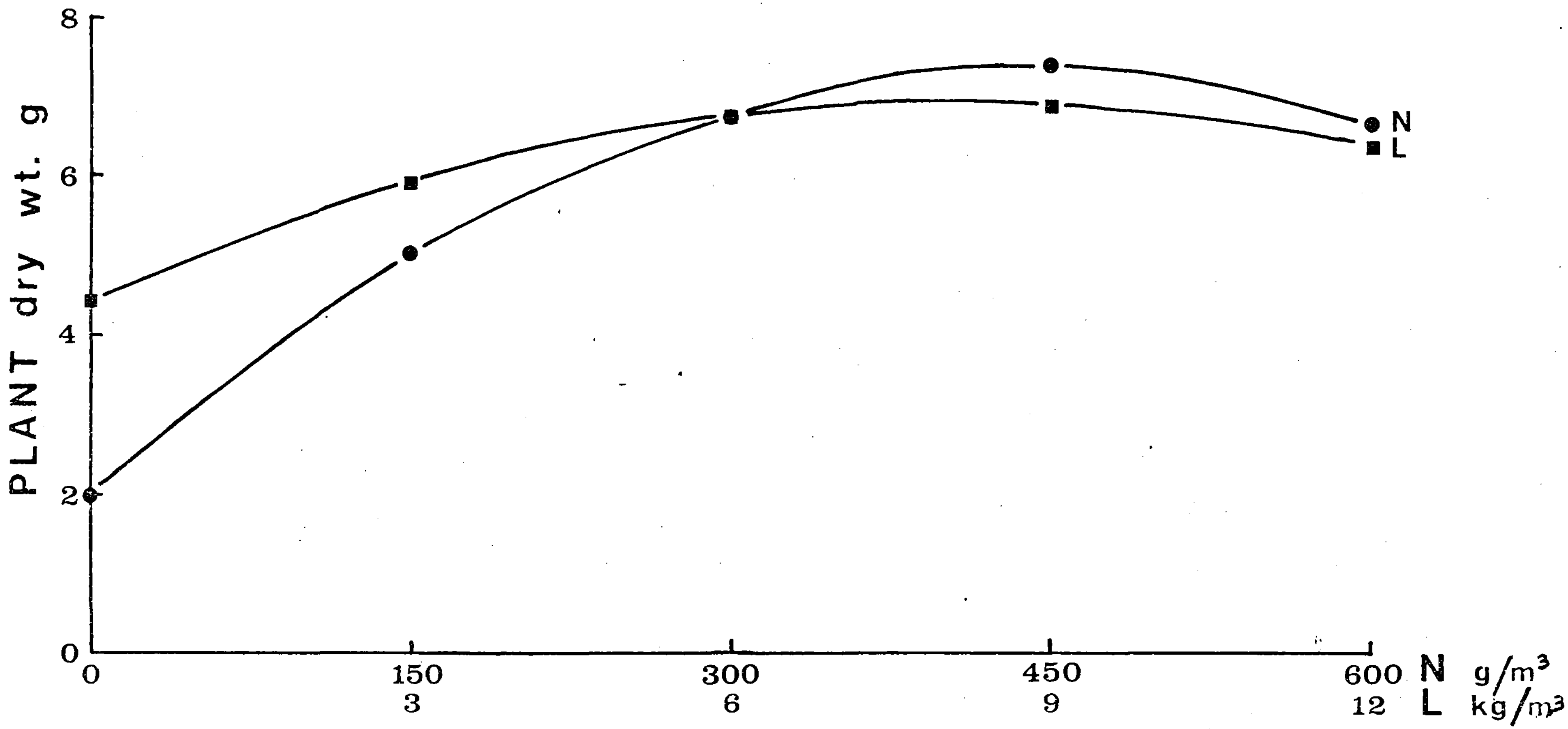

Fig. 1: Expt. E. The influence of N fertilisation and liming on the foliage growth (dry wt. g/plt.) of *Tagetes patula* 'Sparky'.

quadratic response curve appears to be a more appropriate representation of the lime effect than fitting a straight line since growth was depressed at high rates, even though the former only approached significance at the 8% level. Haynes and Goh (1977) discussed the importance of pH on N uptake and stated that sometimes NH_4-N toxicity can be overcome by addition of $CaCO_3$. This may account for the benefit of liming especially since Osmocote 26% N releases equal amounts of NH_4-N and NO_3-N.

The additional treatments in Experiment D (Table 5) did not differ significantly from each other which indicated that there was no apparent advantage in using high rates of 8 - 9 month Osmocote nor any advantage between the two media. Marigold Experiment D was only of 2 months duration and therefore the 450/300/250 NPK level from 3 - 4 month Osmocote would be approximately equivalent to the 900/300/250 rate from 8 - 9 month Osmocote (129 v 106g N/m^3/month respectively).

Foliar nutrient levels in marigold were strongly influenced by the fertiliser treatments (Table 6). High N fertilisation more than doubled foliar N levels and increased the uptake of P marginally and of Mg by 50%. Foliar N levels were further enhanced by fertiliser N in the presence of high P additions or in the absence of high K (Table 7). High N additions depressed K uptake but promoted foliar Na levels (Table 5). Very similar results were observed by Tsurishima and Date (1971) for pot grown marigolds using a clay based medium. They also found increased foliar N and Mg and depressed K uptake with high N fertilisation but without apparent statistical analysis. High P levels in the potting mix generally enhanced nutrient uptake (Table 6). Foliar P and Ca levels were strongly increased while Mg uptake was only mildly enhanced (P=9%). Increased N, P, K and Mg was also observed by Tsurishima and Date (1976) when high P levels were used on marigolds although uptake of Ca was less conclusive.

High K fertilisation almost doubled foliar K levels (Table 6) but was antagonistic to N, P (P=7%), Mg and Ca uptake. Very similar results were observed by Tsurishima and Date (1976).

Johnson (1973) examined the visual symptoms and foliar nutrient analyses of a range of flowering annual plants grown in sand cultures containing complete and nutrient deficient Hoagland's solution. Dight (1977) mentioned the importance of examining the foliar nutrient composition of the final product when growing bedding plants and gave a table of typical values from plants grown in peat-based composts. Foliar mineral values were also given by Tsurushima and Date (1976) for a range of bedding plants grown in a soil based potting medium. The range of values from these workers and Experiment D, all for French marigolds, are now presented:

<u>Foliar Analyses For French Marigold</u> (g%)

	N	P	K	Ca	Mg
Dight (1977)	0.7 - 4.0	0.1 - 0.6	0.8 - 3.7	-	-
Johnson (1973)	0.4 - 5.2	0.1 - 0.8	1.0 - 6.0	0.2 - 2.7	0.1 - 2.0
Tsurushima and Date (1976)	1.9 - 4.0	0.7 - 1.1	5.2 - 6.9	1.3 - 3.0	0.2 - 0.7
Experiment D	1.8 - 5.2	0.3 - 0.7	1.5 - 4.0	1.1 - 1.9	0.7 - 1.9

The range of values were relatively similar although the minimum levels in Experiment D did not drop quite as low as those obtained by Johnson (1973), who grew plants in a sand medium without mineral additions. The minimum levels given by Dight (1977) were those at which deficiency symptoms were observed and he concluded that the foliar N content should be above 3% and that K symptoms occur at levels less than 1.5% in the leaf dry matter. Lack of vigour accompanied with stunted growth were the main deficiency symptoms observed in the 2 experiments reported here, apart from some yellowing in N deficient plants.

DISCUSSION ON BEDDING PLANT NUTRITION

Kender and Childers (1959) found that ureaformaldehyde was a very poor source of nitrogen for zinnia seedlings grown in sandy loam and concluded that initial availability of nitrogen was of prime importance. They found that this could be achieved much more satisfactorily with urea. Bunt (1976) pointed out that it is unlikely that even pot plants supplied with ureaformaldehyde would recover more than 50% of the applied nitrogen. Dight (1977) however, did a series of trials some of which were based on ureaformaldehyde. He found that Osmocote 14/6/12 and 26% N and other N sources including liquid feeding were much better N fertiliser sources than ureaformaldehyde. He also noted that initial high levels of N can inhibit growth causing stunting and leaf scorch. This is not a serious risk with Osmocote 26% N since this material has rather a slow release rate initially (Stevens and Thomas, unpublished results). Dight supplied asters and petunias with Osmocote 26% N at 304 and 405g N/m^3 and found this did not promote the same vigour as sulphur coated urea supplying N at 250 or 374 g/m^3. The N release rates from the 2 fertilisers would theoretically have been similar but the Osmocote may have been disadvantaged by a slow start. However Haynes and Goh (1977) found that asters (*Callistephus chinensis*) responded equally well to IBDU, Osmocote 26% N, sulphate of ammonia and urea when grown in peat-sand medium. They also noted that plant recovery of fertiliser N from Osmocote exceeded that from the other 3 fertilisers in the 3 different media used.

Tsurishima and Date (1971) found that French marigolds showed increased fresh weights but not greatly increased heights or width when supplied with additional nitrogen above the general base level used. Vigour and plant quality was improved more by P additions while added K had little influence.

Increasing N, P and K together was not superior to simply adding additional P. The optimal P level for both dianthus and marigold (Experiment E) appeared to be close to 150g P/m^3 but the response was less pronounced than that reported by the former workers.

The optimal N requirements for asters (*Callistephus chinensis*) supplied with ammonium sulphate was found to be 300 - 450g N/m^3 (Haynes and Goh 1977). Some marginal necrosis, thought to be ammonia toxicity, was observed when plants were fed with 600g N/m^3. The optimum level for marigolds was found to be 450g N/m^3 (Figure 1) but no toxicity symptoms were observed above this level. Dight (1977) also noted symptoms of excessive nitrogen, such as dwarfing, and noted that aster was very susceptible while *Tagetes* was found to be only slightly affected. The growth of susceptible species was strongly supressed by rates of 648g N/m^3 (or above) supplied from ammonium nitrate. This was coupled with high NH_4-N levels in the mix, and therefore it is not surprising that toxicity occurred since that rate amounted to at least 432g N released per month (based on a 1½ month release rate). The 300 - 450g N/m^3 found optimal by Haynes and Goh (1977) and reported here for marigolds would amount to between 86 and 129g N/m^3/month.

Dight (1977) stated that potassium is commonly applied in U.K. to peat based composts as potassium nitrate at a rate of 300 - 400g K/m^3. He pointed out that K deficiency symptoms are frequently seen in bedding plants at point of sale. Dianthus and the marigold (Experiment D) grew strongly when added N and K were at high levels. The 3 factor interaction for dianthus indicated that 450g N/m^3 plus 250g K/m^3 coupled with a medium level of P at 150g P/m^3 was the apparent optimum. Very similar levels were also indicated for marigold with possibly slightly higher P levels (Table 4) and a lime rate of 6 kg/m^3 for a peat-sand medium.

CHAPTER 9

NITROGEN RESPONSE OF PROTEACEAE AND OTHER NURSERY PLANTS IN CONTAINERS

ABSTRACT

A range of proteaceous shrubs and other nursery plants were grown in containers with soilless media and various N levels primarily supplied from Osmocote (26% N). Plants demonstrated a range of responsiveness. *Grevillea robusta* was the most responsive but required an optimum near to 120g N/m^3/month, 2 *Eucalyptus* species had smaller responses than *G. robusta* but required an N optimum of 97g N/m^3/month. *Camellia japonica* and *Erica carnea* 'Springwood White' responded best to the range 57 - 121g N/m^3/month. *G. rosmarinifolia* and *Leucadendron adscendens* were the next most responsive species, then *Hakea laurina* and *Dryandra formosa*. *Leucospermum candicans*, *Protea repens*, *P. scolymocephala* could grow satisfactorily on very low N levels amounting to just over 5g N/m^3/month from Osmocote 18/2.6/10. Optimum N rates for all these species are discussed.

INTRODUCTION

Optimum growth of container plants requires a fairly uniform and continuous supply of N but with slightly greater levels in spring (Furuta 1976). Bunt (1976) stressed the relatively greater importance of a continuous N supply for pot plants grown in loamless composts compared with crops grown in borders or the open ground. This was because of inherently low levels of available N, roots restricted to a relatively small volume and the need for frequent watering of plants in containers. Soilless media rich in N would be unsuitable because of difficulties of standardisation, and the need to continually monitor N levels to maintain an optimum N supply. The total N requirement and the rate at which it is required depends on the vigour of the species and the manner in which the plant is grown. Temperature, light, water availability and size of container are the most important factors controlling the rate and amount of growth.

Boyd and Needham (1976) discussed different approaches to the interpretation of data from N experiments and emphasised the value of multi-level tests with from 6 - 9, rather than only 2 - 4, N levels. They also stated their preference for the use of linear segments to describe a quadratic N response rather than a smooth curve since a curve was said to often encourage an over-estimation of crop requirements due to the economic optimum being placed on the crest of the curve rather than on a flat plateau.

Knowledge of the desirable N rate is important. Lack of nitrogen will give rise to plants with low growth rates and often a spindly weak foliage growth, while excessive levels can yield hard stunted plants (Bunt 1976). The use of nitrogen in container mixes was reviewed by Thomas and Spurway (1975 a,b) (Appendix II). It is clearly the single most important factor to consider when examining the nutrition of container grown plants since a continuous supply is required. The rate of supply has a dominant control over plant growth and is influenced by many factors such as fertiliser type, N losses and growing conditions. Furuta (1976) indicated that a theoretical requirement of 3g of 14 month Osmocote required to raise a marketable plant in a one gallon container in practice becomes a 9g basal application because of severe N leaching losses over the production time. Immobilisation of N and denitrification can also account for poor N recovery rates with container grown plants (Goh and Young 1975, Haynes and Goh 1977).

Potted chrysanthemums were shown to have an N uptake rate, and total N demand, over 10 weeks in summer which greatly exceeded the requirements of cyclamen over one year (Bunt 1976). This illustrated the importance of comparative nutrition and in previous chapters N requirements have often been shown to contrast strongly between species. The objective of the experiments discussed in this chapter was to examine several different species (many in the Proteaceae) and to compare their responses to a range of N levels and in one case, different fertiliser sources while other inputs were kept relatively constant.

MATERIALS AND METHODS

Plant Species and Growing Conditions

Six experiments were run with from 1 - 5 species in each one. The plants used, laying - down and harvest dates and numbers of replicates are given in Table 1. All plants were seedlings with the exception of *Grevillea rosmarinifolia* (Experiment A), *Erica carnea* 'Springwood White' (Experiment C), *G.* 'Olympic Flame' (Experiment D) and *Leucospermum candicans* (Experiment E). Rooted cuttings or young seedlings were potted up individually into tubes containing a medium with little or no nutrients. All experiments except B were run in a heated glasshouse equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Experiment B was carried out in a shadehouse covered with 50% polypropylene shadecloth (Sarlon). Hand watering was done when required and no additional fertiliser application were made following laying - down.

Experimental Design

Experiments A, B, D, E, and F were simple designs based on several levels of nitrogen for a range of species which were mostly in the Proteaceae. Experiment C was the only one with a factorial design and involved 2 N levels x 2 N sources (Uramite and Osmocote 26% N). All were randomised block designs.

Media and Fertilisers

The medium for all experiments was equal parts (1:1, vv) Mataura sphagnum peat and fine grade perlite. The physical and chemical properties of Mataura peat were described by Goh and Haynes (1977 a) and perlite by Morrison *et al.* (1960).

The levels of nitrogen in media varied from 0 to 900g N/m^3 (Tables 2-5) and were supplied predominantly from Osmocote (26% N). A basal dressing of 8 - 9 months Osmocote (18/2.6/10) supplying 45g N/m^3 was used in all experiments except those with nil N treatments. Total N was then made up from 3 - 4 month Osmocote (26% N) except in half the treatments in Experiment C, where Uramite (38% N) was used. Base dressings of Osmocote 18/2.6/10 supplied 6.5g of P/m^3 and this was supplemented with superphosphate (9% P) to give a total of 30g P/m^3 in Experiments A, B and F. All other experiments were at the base level of 6.5g P/m^3 from Osmocote 18/2.6/10 or supplied from superphosphate in the nil N treatments. The 8 - 9 month Osmocote yielded 25g K/m^3 and this was made up to 125g K/m^3 in all trials except Experiment C with sulphate of potash (39% K).

The levels of P and K were therefore as follows:

Experiment	P	K
	g/m^3	
A	30	125
B	30	125
C	6.5	25
D	6.5	125
E	6.5	125
F	60	125

A base dressing of the following was also used, in all experiments: 4.5 kg/m^3 dolomite lime, 1.5 kg/m^3 agricultural lime ($CaCO_3$), 75g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB5 (2½l) 'Plantabags' just prior to potting.

Data Collection and Analysis

Visual ratings of foliage were carried out on all plants using the grading system described in Chapter 2. On completion of each experiment the plants were cut-off just above the top of the medium and the foliage was oven dried. All ratings and dry weights were statistically examined using the Teddybear (now Crypto/teddybear) computer programme for analysis of variance and F test.

RESULTS

Experiment A

Lack of added N had no unfavourable effect compared with other treatments on the growth of *Grevillea rosmarinifolia* and *Protea scolymocephala* 3 months after bagging of the plants (Table 2, Figures 1 and 2). However 340 - 450g N/m^3 appeared to be the upper limit for both species and very severe damage was evident after 3 months and death of most plants by harvest time in the 2 highest N treatments. Optimum N levels could not be accurately evaluated in these experiments because N was predominantly applied as 3 - 4 month Osmocote for an experiment which was run for nearly a year. It was noticeable, however, that a total of 225g N/m^3 for grevillea and 100g N/m^3 for protea appeared to be the optimum N level. These rates would amount to an optimum theoretical release rate of 57 and 24g N/m^3 per month respectively with only 5.5g N/m^3/month supplied from the 8 - 9 month Osmocote after 3½ months. Protea was therefore more sensitive than grevillea to increasing N levels although there was a strong similarity in the response of the 2 species to added N and the onset of toxicity at 3 months. This is shown in a comparison between Figures 1 and 2. Tables are used to give statistical analyses of data and figures to illustrate significant response curves only.

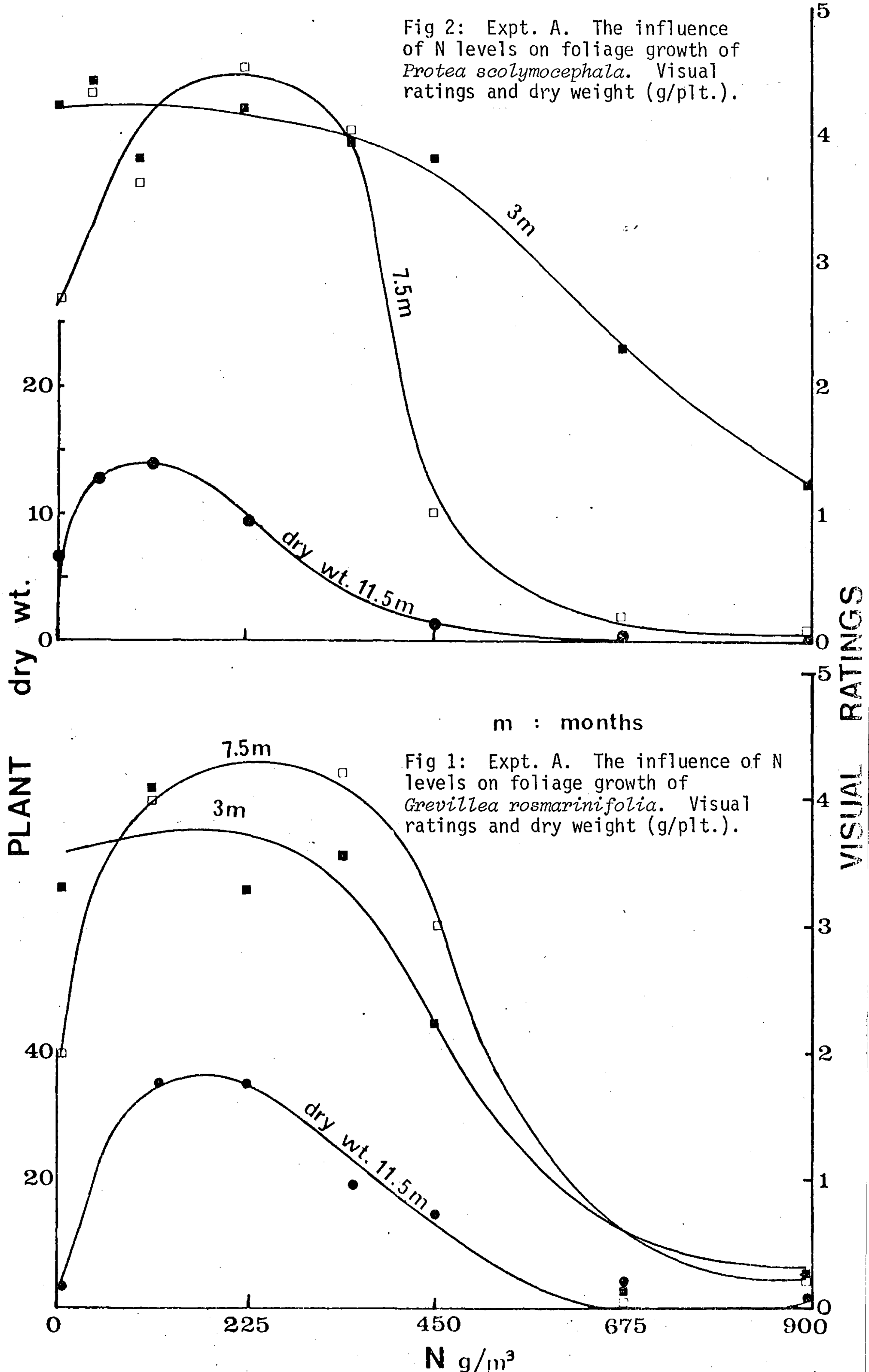

Fig 2: Expt. A. The influence of N levels on foliage growth of *Protea scolymocephala*. Visual ratings and dry weight (g/plt.).

Fig 1: Expt. A. The influence of N levels on foliage growth of *Grevillea rosmarinifolia*. Visual ratings and dry weight (g/plt.).

Experiment B

Foliage of the three species in this experiment was visually rated at approximately 2, 7 and 11 months. There was no apparent response to increasing N levels after 2 months (Table 3) but at 7 months *Camellia japonica* in the nil and 45g N/m^3 treatments were showing N deficiency and there was a similar effect in *Erica carnea* 'Springwood White' and *Hakea laurina* but only with nil N. The growth responses for the 3 species are depicted in Figures 3, 4 and 5.

There was little N toxicity apparent and in fact the camellias and ericas showed no significant growth depression at any stage even with the highest N level of 900g N/m^3/month, theoretically amounting to 250g N/m^3/month for the first 3½ months. Some growth depression would have been expected for camellia and erica, however hakea showed severe toxicity symptoms at 11½ months (Table 3). In all 3 species a total level of between 225 to 450g N/m^3 appeared to be the most desirable. This would amount to between 57g N/m^3/months for hakea and 121g N/m^3/month for the other 2 species for the first 3½ months.

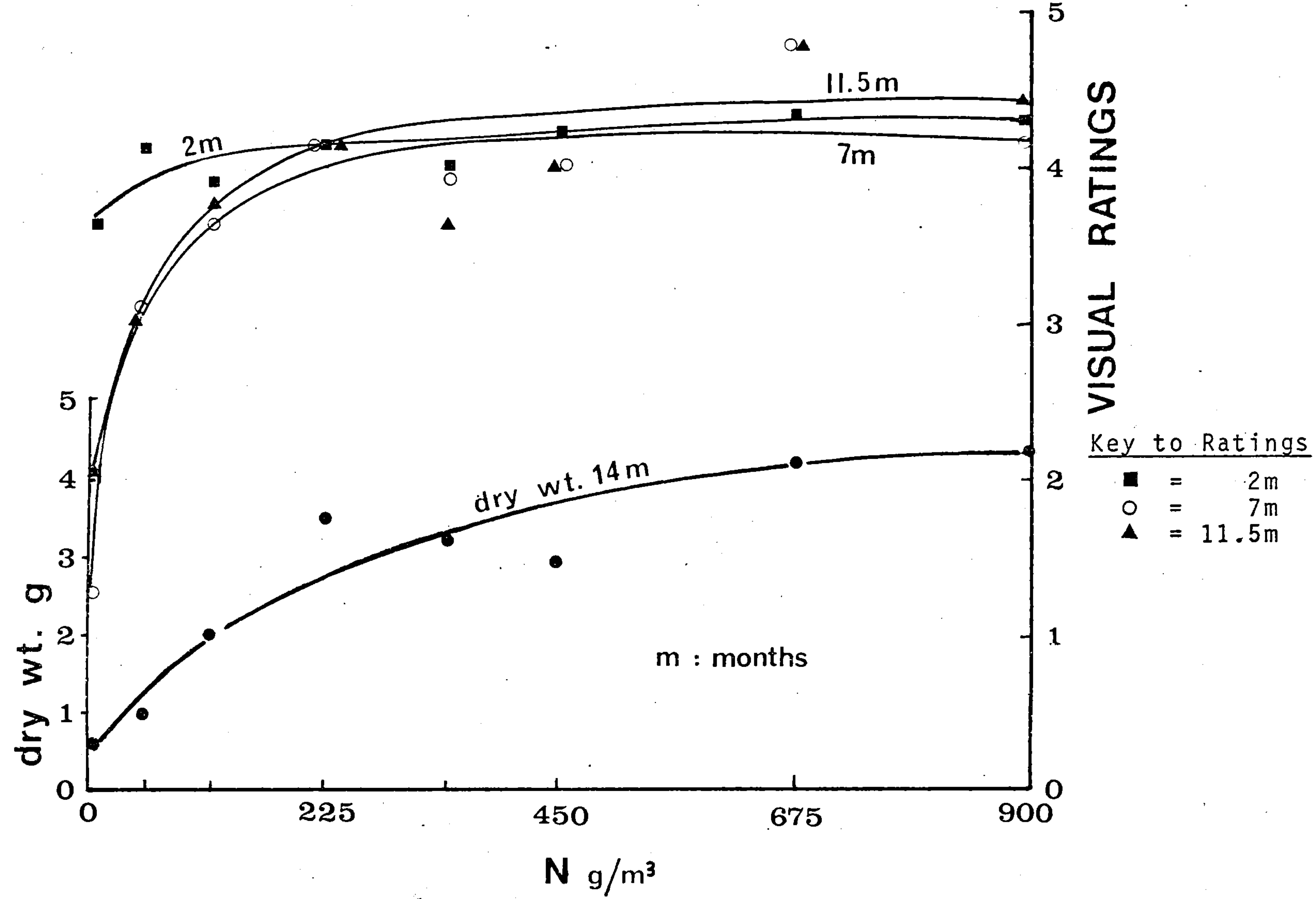

Fig. 3: Expt. B. The influence of N levels on foliage growth of *Camellia japonica*. Visual ratings and dry weight (g/plt.).

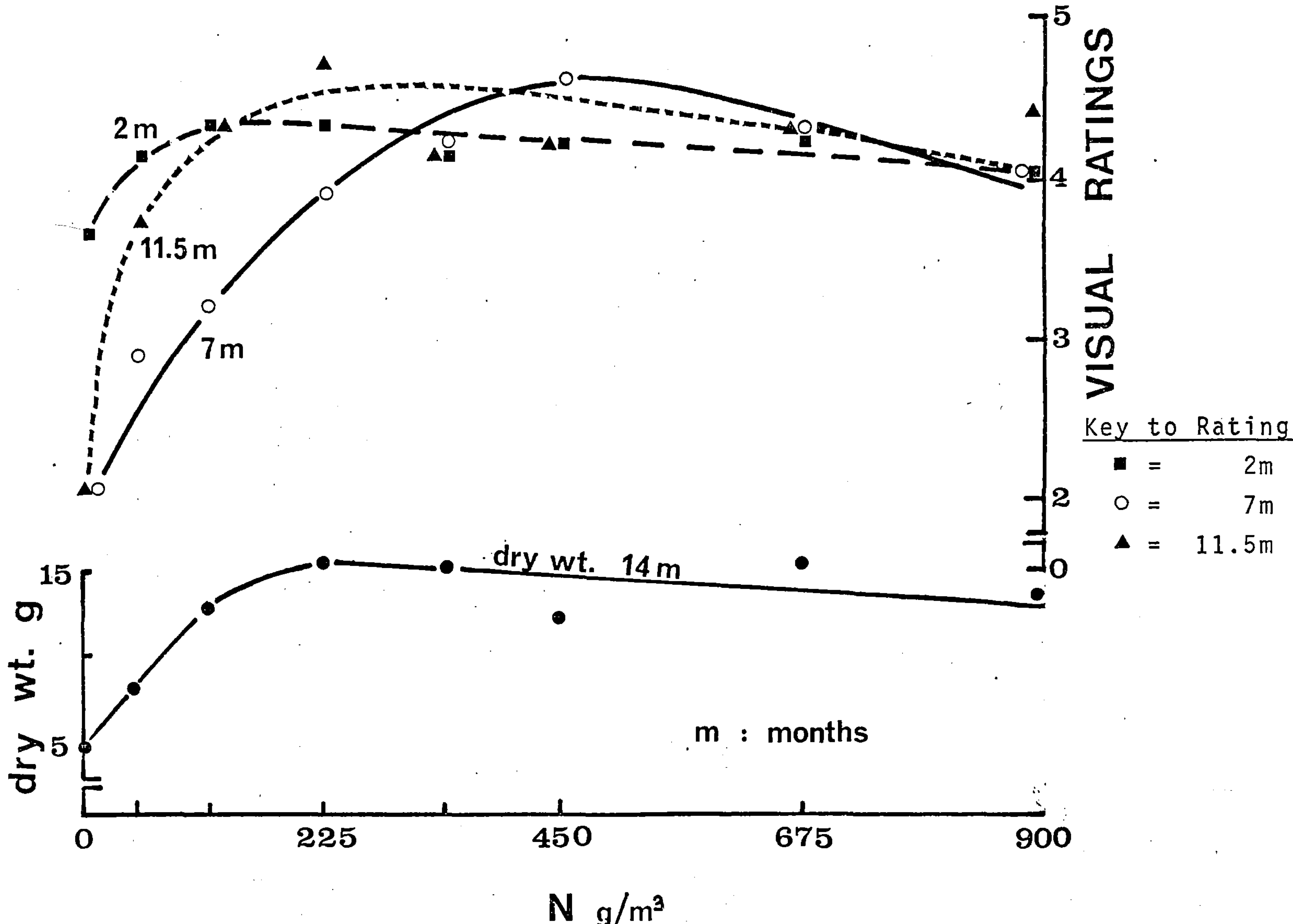

Fig 4: Expt. B. The influence of N levels on foliage growth of *Erica carnea* 'Springwood White'. Visual ratings and dry weight (g/plt.).

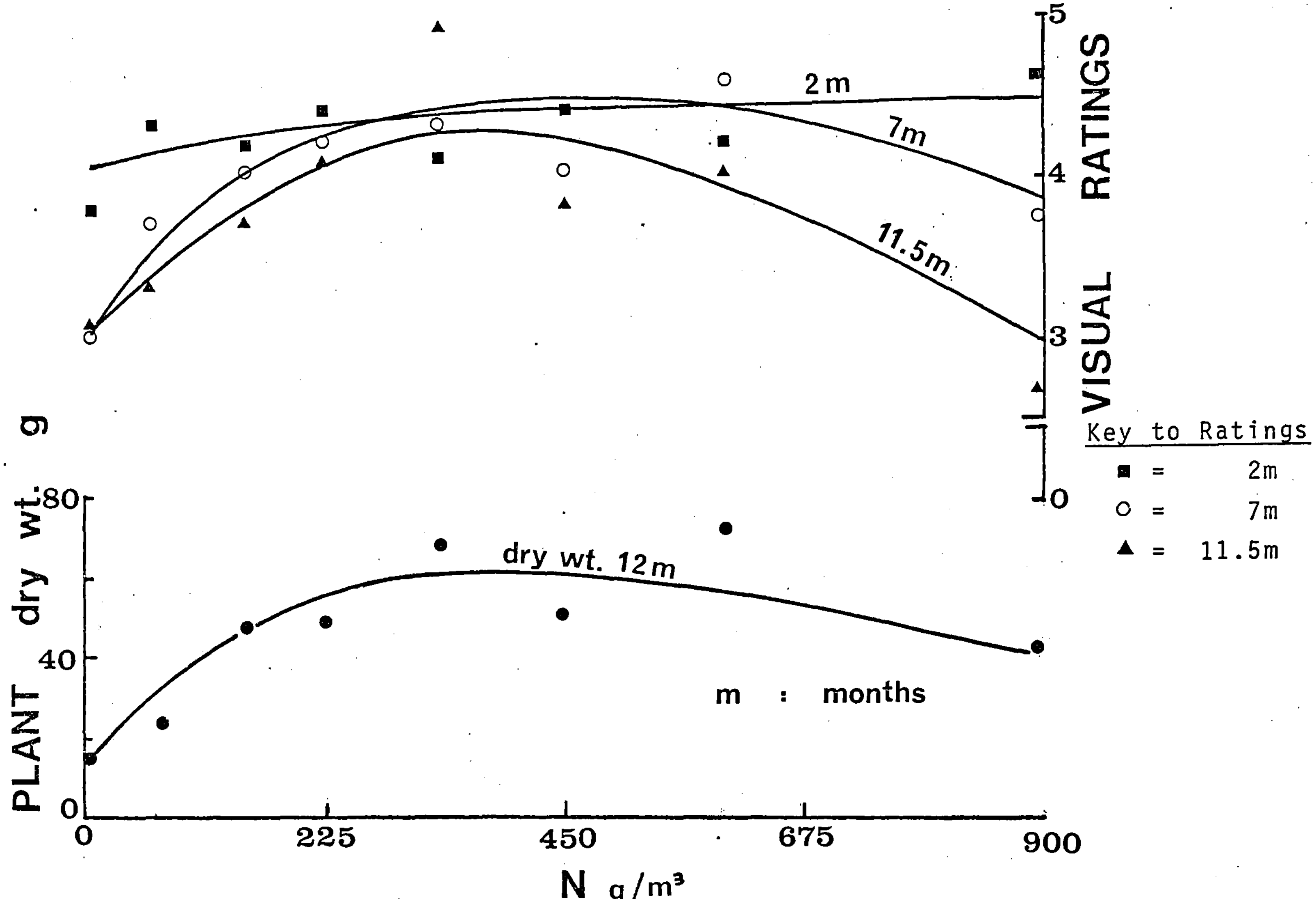

Fig. 5: Expt. B. The influence of N levels on foliage growth of *Hakea laurina*. Visual ratings and dry weight (g/plt.).

Experiment C

This experiment involved *Grevillea* 'Olympic Flame' and *Dryandra formosa* supplied with nitrogen at two rates combined in a factorial design with Uramite and Osmocote. The lower rate of nitrogen appeared quite adequate for dryandra (Table 4) and growth of this species in the 225g N/m^3 rate was almost significantly ($P = 0.07$) higher than in 450g N/m^3 when measured by visual ratings. Uramite initiated higher dry weight yield than Osmocote for Dryandra.

The grevillea responded quite strongly to N rates and type of fertiliser. Osmocote at 450g N/m^3 was superior to the lower rate and to both levels of Uramite (Table 5). This was probably because Uramite can have an N mineralisation rate of less than 60% of 3 - 4 month Osmocote (Bunt 1976) and thus the high N requirements of grevillea compared with hakea could not be met with that fertiliser.

Experiment D

The experiment with *Grevillea robusta* was similar to Experiments A, B and F in that it involved several levels of nitrogen. The nil and 45g N/m^3 treatments quickly became inadequate as shown by visual ratings at 3½ months (Table 6 and Figure 6) while the 110g N/m^3 rate was inferior to the highest level of 675g N/m^3 at 3½ months. The optimum rate appeared to be close to 450g N/m^3 or 120g N/m^3 per month.

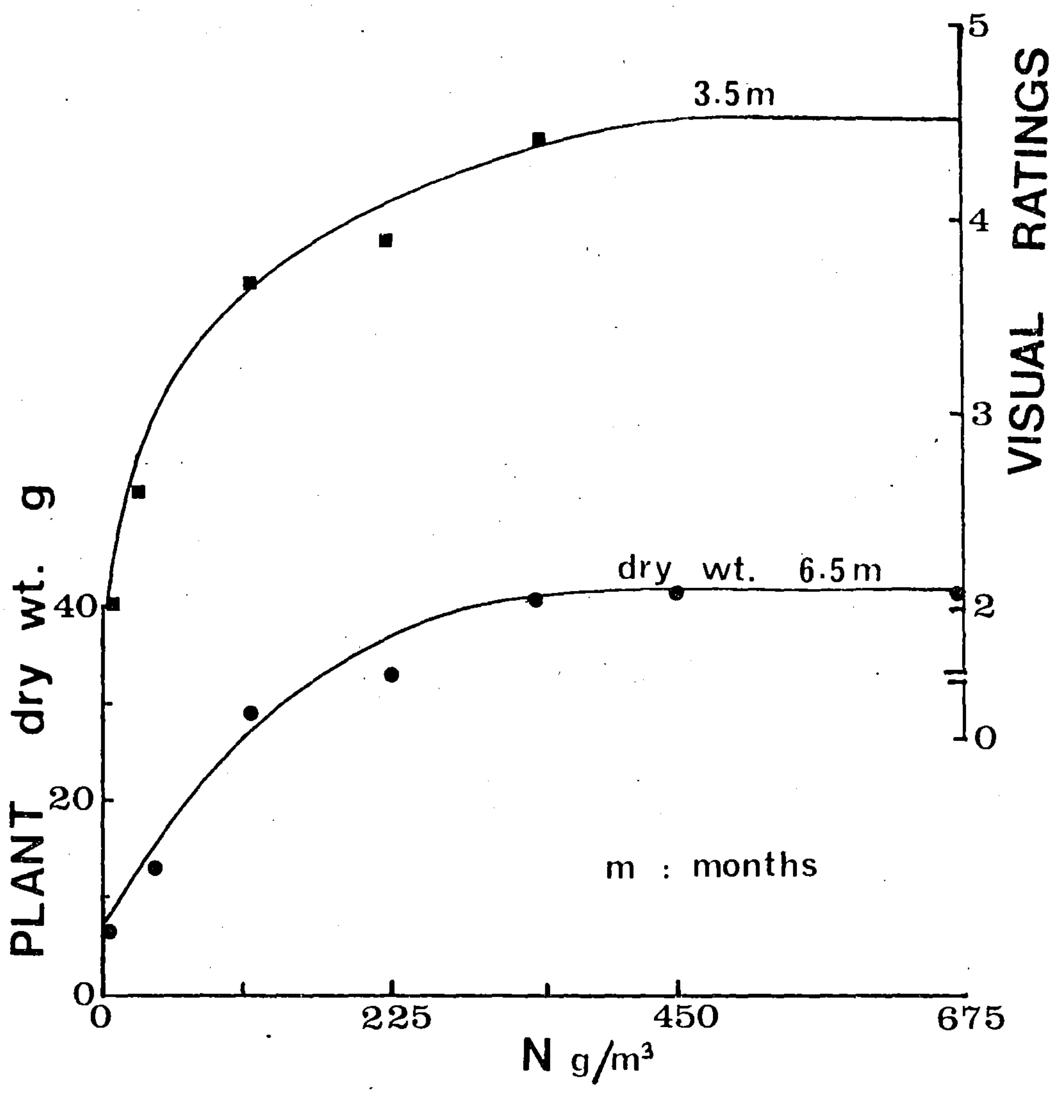

Fig. 6: Expt. D. The influence of N levels on foliage growth of *Grevillea robusta*. Visual rating and dry weight (g/plt.)

Experiment E

A very low and 2 medium rates of N addition were used for 6 proteaceous shrubs (Table 7). The foliage growth of *Grevillea robusta* in the 45g N/m^3 showed the effect of insufficient N after 3½ and 8 months and in final dry weights. *Leucadendron adscendens* was the only other species with a depression in yield with the 45g N/m^3 rate. This occurred only for foliar dry weights and it is noticeable that the other 4 species showed no ill effects or deficiency symptoms when receiving 0.25 kg/m^3 of 8 - 9 month Osmocote. A rate of 45g N/m^3 would amount to only slightly over 5g N/m^3/month. The 450g N/m^3 rate appeared toxic on *G. rosmarinifolia* at 3½ months and *Protea scolymocephala* at 8 months while *Leucospermum candicans* and *P. repens* were similarly unaffected by increasing N levels. This indicates that no serious deficiency was occurring. A lack of N response was most apparent with the proteas where the 45g N/m^3 treatment for *P. scolymocephala* rated significantly higher than the other treatments after 8 months. In addition the dry weights for *P. scolymocephala* species at the very low N treatment were high, although not significantly greater than others-probably because of the high variability (CV = 110%).

The optimum levels of N for *G. robusta* and *L. adscendens* appeared higher than those for other species at between 225 and 450g N/m^3. The protea species and leucospermum appeared least demanding, requiring only 45g N/m^3 (from slow release Osmocote only). *G. rosmarinifolia* from this work and Experiment A would probably be intermediate between the 2 groups.

Experiment F

Two *Eucalyptus* species were grown in media with a range of N levels. There was little difference between plants in all treatments after 2½ months except that plants without N supplied, were noticeably deficient (Table 8). The highest dry weights in both species occurred in plants from the 340 - 675g N/m^3 treatments. The 110g N/m^3 treatment was inferior to these. There was no apparent toxicity and the optimum rate appeared to be fairly close to 340g N/m^3 for both species. This would be equivalent to 97g N/m^3 per month from 3 - 4 month Osmocote.

DISCUSSION

Grevillea rosmarinifolia was grown in Experiments A and E and also studied in Chapters 2, 4 and 6. Higgs (1970) noted that this species could be damaged by high fertiliser rates that did not affect other plants and this was noted in Experiment A where foliage growth was severely depressed in N additions above 450g N/m^3 (Figure 1). A linear response to N rates from split applications of N was demonstrated in Chapter 6 with a maximum application of 86g N/m^3/month. The work reported here indicates that 121g N/m^3/month may be too high for *G. rosmarinifolia*. The optimum is therefore about 100g N/m^3/month. *G. robusta* responded well up to 450g N/m^3 and since this appears to be a robust rapid growing species (as discussed in Chapter 3) it is reasonable to assume that the optimum is higher than for *G. rosmarinifolia* and could be placed at 120g N/m^3/month.

Proteas can tolerate very low nutrient levels (van Staden 1968 b) as found in Experiments A and E and in Chapter 3. These findings indicate that proteas require only low N rates and probabaly 50 - 60g N/m^3/month would be quite adequate particularly if a soil mix was used. Initial propagation would probably need to be done without added fertilisers and using a mix such as equal parts peat and soil. Experiment E indicated that leucospermums are likely to have a similar requirement.

Leucadendron adscendens (Experiment E) *Dryandra formosa* (Experiment C) and *Hakea laurina* (Experiment B and Chapter 4 and 6) all appear to require N levels which are intermediate between proteas and *Grevillea rosmarinifolia* for optimum growth. Hakea was more sensitive to high N levels than *G. rosmarinifolia* (Chapter 4), camellia and erica (Experiment B). A rate of 80g N/m^3/month is probably the upper limit for these species.

Camellias have a relatively slow growth rate and respond unfavourably to moderate salinity levels (Furuta 1969) or high fertiliser rates (Pearson 1958, Wills 1971). Earlier work (discussed in Chapter 3) indicated that camellia has not more than medium N requirements. In Experiment B camellia and erica responded similar and both responded to higher N levels than hakea. Carter (1973) stated that ericas only require low liquid feed rates and others have found them subject to chlorosis with certain fertilisers (Morgan 1973) or media (Anon 1971). Klougart & Bragge Olsen (1969) stated that plants in the Ericaceae and Theaceae are very sensitive to salt damage. It appears from Experiment B and Chapter 7 (for erica) that a level of approximately 80g N/m^3/month would appear to be a suitable general optimum for both genera.

Young eucalypts can respond strongly to N and P sidedressings in the open ground (Cromer *et al.* 1975, McIntyre and Pryor 1974) and these elements are important for their container culture (Kaul *et al.* 1966 a and b, 1968, 1970 a and b). A strong response was noted in Chapter 5 and again here in Experiment F up to a level of 340g N/m^3. They were tolerant of 675g N/m^3 (185g N/m^3/month) and because wide variations in nutrient response have been noted between species (Moore and Keraitis 1971) a broad optimum range of 90 to 130g N/m^3/month is suggested to allow for individual species requirements. In general they respond similarly to *Grevillea robusta* and 120g N/m^3/month should be adequate.

CONCLUSIONS

The differing N requirements of a group of species was demonstrated. The range within the Proteaceae was very wide and native habitat was probably the dominant governing factor influencing the N responses. *Grevillea robusta* showed a high requirement (120g N/m^3/month), *G. rosmarinifolia* was intermediate (approximately 80g N/m^3/month) and *Protea* spp. low N needs (50g N/m^3/month).

Nitrogen was supplied from different fertiliser sources and it was concluded that Uramite which is a relatively poor N source in a soilless mix was more suitable for *Dryandra formosa* than *G.* 'Olympic Flame', while Osmocote (26% N) was the better fertiliser source for grevillea. This was because dryandra is similar to protea in having a low N requirement and therefore a poor fertiliser source or a low rate of a more efficient fertiliser than Uramite is desirable.

Hakea laurina appeared similar to *D. formosa* and had a lower N requirement than camellia and erica. *Leucadendron adscendens* had similar N requirements to *G. rosmarinifolia* but *Leucospermum candicans* would appear to grow best with N levels which are intermediate between the optima for *G. rosmarinifolia* and *Protea* spp.

Camellia japonica and *Erica carnea* 'Springwood White' are temperate species which were found to have low to medium N requirements with an optimum of approximately 80g N/m^3/month. It was suggested (Chapter 3) that the temperate forests in which *Camellia japonica* developed were not very fertile and this would partly explain this camellia's low to medium N requirement. Growth rate may also be an important factor influencing the nutritional requirements of camellia and erica. They contrast with eucalypts which have a rapid growth rate and were found to grow strongly in response to 90g N/m^3/month. However habitat is usually implicated and as discussed earlier (Chapter 5) genotype and habitat been shown to influence N utilisation in eucalypts (Moore and Keraitis 1971).

CHAPTER 10

PHOSPHORUS RESPONSE OF PROTEACEAE AND OTHER NURSERY PLANTS IN CONTAINERS

ABSTRACT

A range of mostly proteaceous shrubs was grown in containers with various P rates. Shrubs in the Proteaceae were generally intolerant of P levels about 50 g/m^3 but *Grevillea robusta* and *Leucospermum candicans* were not damaged at 120g P/m^3. *Camellia japonica* could tolerate levels of about 125g P/m^3 and this rate appeared optimal for the *E. carnea* 'Springwood White'. *Protea scolymocephala* growth was more satisfactory in peat:perlite (1:1, vv) than peat:perlite:soil (1:1:1, vv) and liming tended to reduce P toxicity. Foliage growth was more severely depressed by the high P rate (60g P/m^3) with the soil medium than in peat-perlite.

INTRODUCTION

Many of the cultivated Australian Proteaceae come from heathlands where the soils are often extremely impoverished (Specht 1963, Stewart 1959, Wood 1959). Beadle (1962) pointed out that P levels may be below 150 ppm in some soils. South African Proteaceae are also primarily confined to deficient soils in their native habitat (Johnson and Briggs 1974, Wild 1969). Many Proteaceae have adapted to a low P supply (Beadle 1968, Jeffrey 1967). Some can store P and use it in the growing season (Specht and Groves 1966) while others can revert to a semi dormant state when P and N levels are reduced (Wood 1959). The development of proteoid roots has occurred as an aid to nutrient absorption, particularly P (Purnell 1960, Groves 1964, Jeffrey 1967). This specialised root system is highly efficient at extracting P from the rooting medium (Jeffrey 1967) but can act to the plants detriment if high levels of available P are present particularly within the small confines of a nursery container. Earlier chapters have indicated that *Grevillea rosmarinifolia, Hakea laurina* and particularly *Protea* repens were readily damaged by medium levels of added P in a potting mix. Other genera from Australia were also implicated.

There is probably a tendency in New Zealand nurseries to add medium quantities (1kg/m^3) of superphosphate along with slow release fertilisers, such as Osmocote, which may already contain some P. This is based on observations and appears to be due to the fact that New Zealand farming is based on the extensive use of superphosphate as the key and often sole fertiliser in the 'clover based pastoral industry'. Phosphorus can be toxic for even such crops as cereals on light lands (Loneragan *et al.* 1966). Many Australian shrubs and trees are grown in New Zealand nurseries plus other species which may be sensitive to added P and therefore it appears justified to look at the influence of several P levels on a range of nursery species. A further objective was to examine the combined effect of P additions and liming on plant growth since pH of the medium can strongly influence P concentrations in the soil solution (Tisdale and Nelson 1970).

MATERIALS AND METHODS

Plant Species and Growing Conditions

Four separate experiments were carried out each involving from 1 to 5 species and a total of 880 plants. The plants used and the laying-down and harvest dates are given in Table 1. Most plants were raised from seed and pricked out into tubes where they were held with little or no feeding until the experiments began. *Grevillea rosmarinifolia* (Experiment A and C), *Erica carnea* 'Springwood White' (Experiment C) and *Leucospermum candicans* were grown from semi-ripe tip cuttings and held in tubes as were the seedlings. All experiments were run in the same heated glass-house which was equipped with automatic fan ventilation. The minimum glasshouse temperature was 15^{o}C while the maximum was close to 5^{o}C above ambient temperature. Hand watering was done when required and no further fertiliser applications were made following laying-down.

Experimental Design

Experiments A, B and C were simple designs based on several levels of phosphate for a range of species which were mostly in the Proteaceae. Experiment D differed in that only *Protea scolymocephala* was involved and that it was a factorial experiment with 3 levels of P x 2 media (soil and soil-less) x 3 lime levels and duplicated with two sizes of plant. The small sized plants were approximately 6cm high and had been propagated in tubes, while the larger ones were nearly double this size, well branched and had been growing in 10cm Ace pots. The number of replicates and treatments are given in Table 1.

Media and Fertilisers

A mixture of equal parts of Mataura sphagnum peat and fine grade perlite was used for all experiments. A medium made up of equal parts of sphagnum peat, perlite and soil were used as one factor in Experiment D only. The physical and chemical properties of Mataura peat were described by Goh and Haynes (1977a) and perlite by Morrison *et al.* (1960).

The soil was Wakanui clay silt loam, taken from the top 15cm of cultivated ground. The soil's characteristics were as follows: pH 5.9, soluble P 5%, organic C 3.1%, total N 0.18%, C/N 17, cation exchange capacity 10.3me./100ml, total bases 5.4me./100ml and base saturation 52.4%.

Levels of added P varied from 0 to 300 g/m^3 (Tables 2-5) and were predominantly supplied from single superphosphate (9% P). Dolomite and agricultural ($CaCO_3$) limes were used in the ratio of 3:1 (w.w) at 6 kg/m^3 in experiments A, B and C and at 3, 6 and 12 kg/m^3 for D. Levels of other nutrients in experiments A, B and were 150g N/m^3 and 75g K/m^3 supplied from 3 - 4 month Osmocote (26% N) and sulphate of potash (39% K) respectively. The levels in Experiment C were 225g N/m^3 and 125g K/m^3 which were all supplied from 8 - 9 month Osmocote (18/2.6/10). This meant that in all treatments in Experiment C there was a base level of 32.5g of slow release P with the remaining amount derived from superphosphate. Single superphosphate was the sole source of P in the other 3 experiments. All treatments also received a basal dressing of the following: 75 g/m^3 'Sequestrene' iron chelate (Na EDTA Fe with 12% iron) and 'Sporumix A' (150 g/m^3 containing 1.14% B, 0.62% Zn, 1.27% Cu, 5.46% Mn, 0.06% Mo, 0.05% Co, 9.78% Mg). The media and fertilisers were well mixed and then transferred to PB 5 (2½l) 'Plantabags' just prior to potting.

Two media samples were taken on two occasions randomly from the treatments in Experiment D and the mean pH's were as follows:-

			pH					
			3 months			6½ months		
			Lime (kg/m^3)			Lime (kg/m^3)		
			3	6	12	3	6	12
	15	PP	5.6	6.5	6.2	4.6	6.0	6.6
		PPS	5.6	6.3	6.5	5.7	6.0	6.4
P	30	PP	5.3	5.2	6.7	5.5	5.6	6.7
(g/m^3)		PPS	5.4	5.9	6.7	5.3	5.8	6.7
	60	PP	5.2	5.5	6.4	5.3	5.8	6.3
		PPS	5.7	5.7	6.6	5.6	5.7	6.5
Mean			5.5	5.4	6.5	5.3	5.8	6.5

Data Collection and Analysis

Visual ratings were carried-out on all plants using the grading system outlined in Chapter 2.

On completion of each experiment plants were cut-off just above the top of the medium and the foliage oven dried. All ratings and dry weights were statistically examined using Teddybear (now Cryto/teddybear) computer programme for analysis of variance and F test.

RESULTS

Experiment A

Grevillea robusta and *Leucospermum candicans* failed to respond significantly to any treatment, were unaffected by high P levels and in fact the latter produced larger plants than the low P treatment (Table 2). *G. rosmarinifolia, Leucadendron adscendens, Protea repens* and *P. scolymocephala* on the other hand all showed very severe P toxicity symptoms or appeared dead at 3½ months when supplied with 120g P/m^3. This is equivalent to 1.3kg of superphosphate per cubic metre and it clearly had a rapid effect from which there was little recovery by these sensitive species. There was no response to the 30g P/m^3 rate by any of the species, nor was there indication of damage by this low rate.

Experiment B

The three proteaceous species in this experiment were all similar in their high sensitivity to added phosphate. Plants receiving 120g P/m^3 were very severely damaged in the first few months of this experiments with many dead before its full duration (Table 3). There was even severe toxicity noticed with 60g P/m^3 after 4 months. This is equivalent to only 0.6 kg superphosphate/m^3. Dry weight of foliage of dryandra and telopea plants grown with 60 or 120g P/m^3 was inferior to that in plants receiving lower rates. This occurred at only 15g P/m^3 for banksia. There was no evidence of a positive growth response to added P in any treatments.

Experiment C

Five species were grown with 10 levels of added phosphate (Table 4). Results with *Camellia japonica* were rather inconclusive but it appears that this species has no high requirement for phosphate and nor is it readily damaged by P at 300 g/m^3 (equivalant to superphosphate at 3 kg/m^3).

Phosphate at 50 - 75 g/m^3 appeared to be adequate for this species. These rates are quite low since the base dressing of 1.25 kg/m^3 of Osmocote 18/2.6/10 would supply 32.5g P/m^3 over 8 - 9 months (superphosphate was the sole source of P in the other 3 experiments). The rates of 50 and 75g P/m^3 included 17.5 and 42.5g P/m^3 from superphosphate respectively. *Erica carnea* 'Springwood White' was the other non proteaceous shrub in this experiment and showed no deficiency symptoms at 1½ or 2½ months, however 50 and 75g P/m^3 were inadequate for erica at 5 months and at harvest (8 months) resulting in depressed foliar yields. Added P at 150 - 175 g/m^3 mildly depressed erica foliar growth as indicated by foliar dry weights. The main feature, which started to become apparent at 5 months and in the dry weights was that between 100 - 125g P/m^3 was the optimal level for this erica.

Grevillea rosmarinifolia, Hakea laurina and *Protea scolymocephala* were the proteaceous shrubs in this experiment and reacted quite differently to added P than did the previous two species. The lowest rate of 50g P/m^3 was soon observed to be the maximum acceptable level of phosphorus (Table 4). All data is given in Table 4 along with statistical analyses while Figures 1 and 2 are included to illustrate response curves for significant results for hakea and protea respectively. Rates above 100g P/m^3 depressed growth of all 3 species after only 1½ months, and the 4 highest levels caused very severe toxicity in hakea and protea at this early stage. Grevillea ratings after 2½ months showed a continuing depression of growth but by 5 months plants were recovering, probably due in part to leaching and fixation of available P. The other 2 species showed no recovery and with the protea there were only a few plants left alive at 100g P/m^3 with all others dead except for the lowest P level. No positive growth response occurred in protea with P additions and the results were all unfavourable.

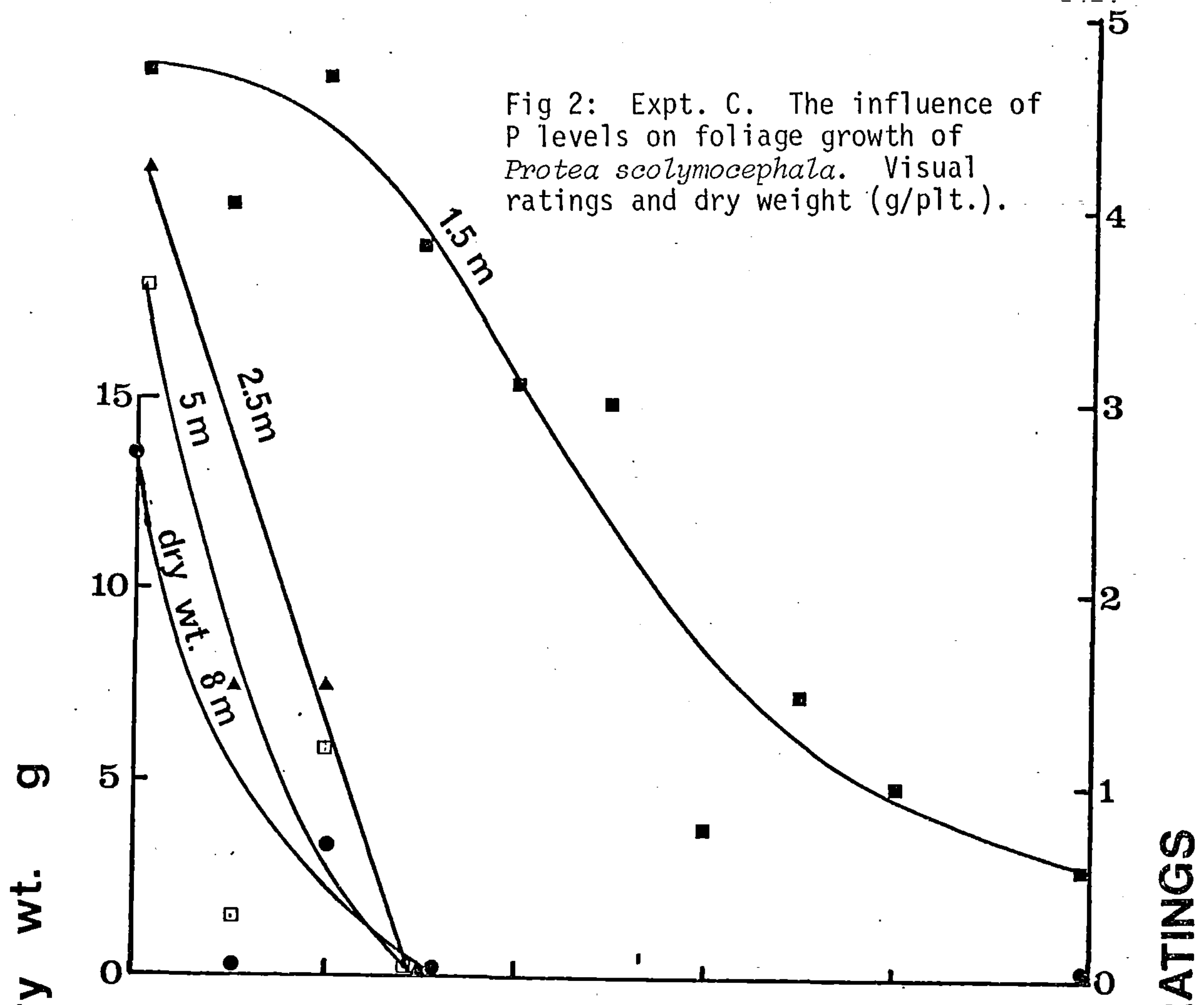

Fig 2: Expt. C. The influence of P levels on foliage growth of *Protea scolymocephala*. Visual ratings and dry weight (g/plt.).

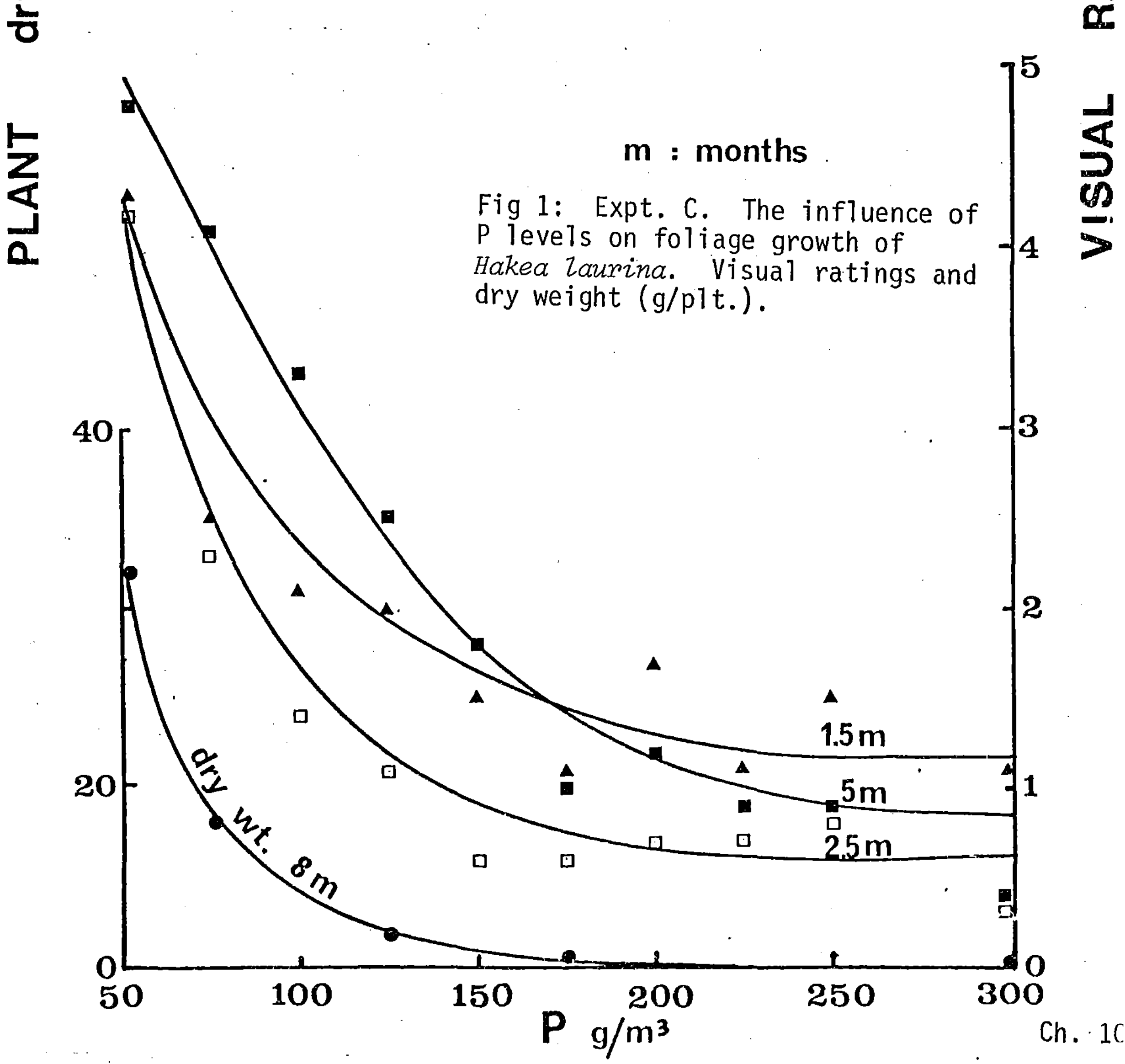

Fig 1: Expt. C. The influence of P levels on foliage growth of *Hakea laurina*. Visual ratings and dry weight (g/plt.).

Experiment D

This experiment was more complex than the previous three and involved 2 factorial experiments designed to examine the influence of plant size, P, lime and media on the growth of *Protea scolymocephala*. The main effects and treatment levels are shown in Table 5.

The peat:perlite (PP) mix gave superior results for the small grade plants at both visual ratings compared to the peat:perlite:soil (PPS) medium (Table 5) and this preference for no soil was also expressed in the foliar dry weights. The media had a similar effect on the large grade plants although it was noticeable, particularly at the second rating, that the quality grades in both media appeared much higher than for the small plants. Dry weights of these large grade plants also indicated strong growth supression caused by the soil potting medium but this effect was more severe with high added P. Thus the large plants growing in PPS and receiving 60g P/m^3 were markedly inferior, at the first visual rating and in dry weight, to plants receiving equal rates of phosphate in PP or lower rates of P in PPS (Table 7). The interaction of P levels and the medium was less clear with the 'small grade' plants since only a 3 factor interaction was significant for each of the ratings and dry weights for these treatments (Table 6). These plants in PPS generally had lower foliar dry weights than those in PP with equal lime and P rates, however those in PPS plus low lime and P grew quite well and were significantly greater than in all other treatments.

Phosphate was not strongly toxic at the levels used. Its effect appeared influenced by lime rate and generally the small size plants were of highest grade or dry weight when P and lime rates were at their lowest (Table 6). However, the 3 factor interactions indicated that this was mostly for plants in PPS and that those in PP grew very well if P and lime rates were increased together. The best 3-treatment combinations for small plants in PP were thus 15g P/m^3 + 3 kg/m^3 Lime (pH 4.6), 30g

P/m^3 + 6 kg/m^3 lime (pH 5.6) and 60g P/m^3 + 12 kg/m^3 lime (pH 6.4). Similar results were obtained with the larger sized plants (Table 7). The large sized plants grew well with a combination of low P and lime rates but for both media in the second rating and for foliar dry weights, appearance and foliar yields were highest when medium P and high lime were combined. This was particularly marked in the latter case where 30g P/m^3 plus 12 Kg/m^3 lime was strongly superior to all other treatments.

DISCUSSION

Soil phosphate was found to be an important determinant in the development of plant communities in the Australian heath vegetation in early studies by Specht (1963) and in subsequent studies (Heddle and Specht, 1975). *Banksia, Grevillea* and *Hakea* often occur together in these communities in various parts of Australia and *Dryandra* may also be present (Lamont 1973). *Telopea speciosissima* occurs in a more restricted habitat on Hawkesbury sandstone but was found here to react in a similar way to the other P sensitive species. The South African proteaceous shrubs were equally sensitive to added P except *Leucospermum candicans*. Eliovson (1967) states that *L. album* and *L. candicans* are similar and that the former grows easily in the garden while both are common in the South Western region of the Cape in South Africa. *L. candicans* appeared to be a robust plant which was easy to propagate and far from difficult to grow in containers. Further work is required to confirm whether this and other *Leucospermum* spp. are similar to *G. robusta* in being able to tolerate high P levels. There was no indication of P toxicity at 120g P/m^3 for *L. candicans* in Experiment A at any stage yet *Leucadendron adscendens* , which is also widespread in a similar habitat, was strongly suppressed by the same P rate.

Camellia and erica are sensitive to high fertiliser levels (Carter 1973, Pearson 1958, Wills 1971) and salinity (Klougart & Bragge Olsen (1969). *C. japonica* growth can be depressed by 300g P/m^3 especially when coupled with high N levels (Chapter 3). The opposite occurred with *Erica carnea* 'Springwood White' (Chapter 7) where there was a positive NP interaction. These species are therefore not similar although both are much more tolerant of added P than most Proteaceae. A level of 100g P/m^3 could be recommended (from Experiment B) for *C. japonica* while both the composite experiment reported in Chapter 7 and Experiment C here would indicate that at least 200g P/m^3 should be basally applied for container grown *E. carnea* 'Springwood White'.

The influence of P additions on the growth of *Grevillea rosmarinifolia* in containers was previously reported in Chapters 2, 4 and 6, accompanied by *Hakea laurina* in the latter two. This grevillea was less sensitive to P toxicity than the hakea, and the upper limit for basally applied P is probably close to 100 g/m^3 for *G. rosmarinifolia* and 50 g/m^3 for *H. laurina*. There has been little evidence of any benefit from adding any superphosphate along with slow release fertilisers indeed with *Banksia spinulosa* in Experiment B foliar ratings and dry weights were inferior with 30g P/m^3 compared to 15g P/m^3. These are low rates and only amount to 333 and 167 g/m^3 of superphosphate (9% P). It is therefore inadvisable to add any superphosphate to media for sensitive species. Small grade *Protea scolymocephala* plants were only slightly more affected by added P than large grade ones but at, and following, the pricking out stage even 0.25 kg/m^3 of 8 - 9 month Osmocote has been found to be damaging. It is particularly important to maintain low P levels in the mix when medium or high levels of N are present as indicated in Chapters 2, 3 and 4 and by Grundon (1972).

Grundon (1972) stated that several heathland Proteaceae are like the calcifuges since they are adapted to maximum growth at low available Ca levels, but in contrast to most of the European calcifuges they are unable to avoid excessive uptake of calcium which leads to severe depression of yield. *Protea scolymocephala* however, in the work reported here, was very tolerant of high lime rates. The pH was raised from 5.4 at 3kg lime/m^3 to a pH of 6.5 at the 12 kg rate after 6½ months. There appeared to be no unfavourable response or negative interaction between lime and P, and plants appeared to grow equally well at 60g P/m^3 plus 12 kg lime/m^3 as when both factors were applied at low rates. In fact with large grade plants the highest foliar dry weights were 30g P+12 kg lime per m^3. Massey and Winsor (1973) noted that liming decreased the soil test values for P when the pH of a glasshouse soil was raised from 5.6 to 7.4 and Bunt (1976) has noted similar effects in potting mixes. Tisdale and Nelson (1970) state that the concentration of the various phosphate ions in the soil solution is intimately related to the pH of the medium and that in alkaline or calcareous soils this is governed primarily by Ca++ activity, the amount and particle size of free calcium carbonate and the amount of clay present. It therefore seems plausable that high lime rates could have influenced P availability as indicated by the growth responses of *P. scolymocephala* and that high lime rates (greater than 6 kg/m^3) will reduce the possibility of P toxicity. It was also noticeable that the soil mix, which grew inferior plants compared to PP, accentuated the P toxicity as occurred in Chapter 4. Hence a negative interaction between toxic P levels and an inferior physical medium can occur.

CONCLUSIONS

A standardised system of growing plants in soilless media supplied with commercial type fertilisers proved to be a satisfactory method of studying the comparative nutrition of a range of species. It allowed the use of factorial experiments while still retaining direct relevance to commercial practise.

This work has helped overcome some of the problems encountered by New Zealand nurserymen in the container culture of proteaceous shrubs particularly with added P levels. It has also demonstrated the widely differing nutritional requirements of container grown plants. The fertiliser responses of plant species generally reflect the soil fertility of their native habitat which can often have more significance than botanical relationships.

It is convenient for nurserymen to use the same potting medium for as many species as possible but the studies reported here indicate that maximum foliage growth can only be achieved with a wider range of different media for shrubs than is currently being used in most New Zealand nurseries. Modification of commercial seedling and pot plant media by increasing the range of basic mixes and/or using supplementary fertiliser sidedressings is also indicated.

PRACTICAL IMPLICATIONS

Nitrogen Requirements

Nitrogen is probabaly the most important single element in terms of the practical management of loamless potting media. The general significance and estimation of N levels is discussed in Appendix II in the papers by Thomas and Spurway (1974). The comparative nutrition studies reported in this thesis reinforced the dominant importance of N in potting media and also showed that requirements will vary according to the species. Four groupings are suggested according to N requirements:-

Low N Species

(50g N/m^3/month e.g. 2.5 kg/m^3 Osmocote 18/2.6/10)

Banksia		*Leucospermum*
Dryandra		*Protea*
Leucadendron	(slow growing species)	*Telopea*

Medium N Species

(75g N/m^3/month e.g. 3.5 kg/m^3 Osmocote 18/2.6/10)

Camellia

Fatsia

Grevillea (slow growing species)

Hakea

Leucadendron (vigorous species e.g. *L. adscendens*)

Moderately High N Species

(100g N/m^3/month) e.g. 4.5 kg/m^3 Osmocote 18/2.6/10

or 2.5 kg/m^3 Osmocote 14/6/12 for seedlings.)

Acacia

Boronia (slow growing species may be better with medium N.)

Callistemon

Choisya

Erica

Eucalyptus

Grevillea (vigorous species e.g. *G. rosmarinifolia* and *G. robusta*)

Bedding plant seedlings.

High N Species

(120g N/m^3/month)

Ficus (e.g. 5.5 kg/m^3 Osmocote 18/2.6/10)

Tomato seedlings (e.g. 3 kg/m^3 Osmocote 14/6/12)

Phosphate Requirements

Phosphate applications for the proteaceae should be kept to a minimum and no superphosphate should be added to supplement basal applications of Osmocote - this is particularly important at high N levels. Fertilisers high in P, such as Magamp, should be avoided. The only exceptions to this are the rain forest species such as *Grevillea robusta* and *Macadamia* spp.

Species can be classified into groups according to their P requirements or tolerance to added P:-

Species Intolerant Of 100-300g P/m^3

Highly Sensitive	Moderately Sensitive	Mildly sensitive
Banksia spinulosa	*Grevillea rosmarinifolia*	*Acacia verticillata*
Dryandra formosa	*Leucospermum candicans*	*Boronia megastigma*
Hakea laurina		*Camellia japonica*
Leucadendron adscendens		
Protea spp.		
Telopea speciosissima		

Species Showing A Response To 100-300g P/m^3

Mildly Responsive	Moderately Responsive	Highly Responsive
Erica carnea	*Dianthus chinensis*	*Ficus elastica*
Eucalyptus spp.	*Tagetes patula*	
Grevillea robusta		
Tomato (young seedlings only)		

Potassium Requirements

Proteaceous shrubs have a low requirment for added K while medium levels (250g K/m^3) are not detrimental. Several Australian shrubs and trees, and some Northern Hemisphere species are also unresponsive to K fertilisation.

Herbaceous seedlings contrast with most woody species and have a moderate to high K requirement. Tomato in particular has a very high need for K and strong foliage growth will be achieved in a peat/sand mix supplied with up to 500g K/m^3 along with 6 kg/m^3 lime and 120g N/m^3 per month. *Ficus elastica* is one woody species which, grown as pot plants, responds strongly to added K although N and P levels must also be high.

Liming

Most proteaceous shrubs can be grown satisfactorily in equal parts peat/sand (PS), peat/perlite (PP) or similar potting media, with 3 kg/m^3 of lime or with no lime added providing that the pH is not below 4.5. However rainforest species such as *Grevillea robusta* may prefer lime rates between 3-6 kg/m^3 particularly where medium or high fertiliser rates are being used in a soilless mix. A lime rate of 6 or more kg/m^3 would be beneficial for proteas (except for calcifuge species) where 30 or more g P/m^3 are added to a potting mix. This could occur where these P levels are derived from application of balanced NPK fertilisers. Liming can help reduce P toxicity although the simpler approach of minimising added P levels by choice of suitable low analysis fertilisers would be preferable. Single element materials such as Uramite and IBDU could be chosen and complete NPK materials such as Magamp should be avoided.

Marigolds in PS or PP require at least 6 kg/m^3 of lime (or sufficient to obtain a pH of approximately 5.5) for optimum vegetative growth. Ericas are typical calcifuge plants and a medium of PS or PP without added lime but with trace elements supplied is most suitable for good foliage growth providing the pH is not greatly below 4.5.

Media

A good open well aerated medium is desirable for proteaceous plants. A mix containing 25-50% soil will not prevent P toxicity and in fact a high proportion of soil could compound any problems associated with excess P levels since plants in an inferior potting medium are more seriously affected than those where only one unfavourable growth factor occurs. However soil can be used to advantage where a safe and low nutrient supply is required. This is of greatest value when plants are very young since when they are small they are most sensitive to added fertilisers (N and P especially). A rate of only 0.25 kg/m^3 of 8-9 month Osmocote (NPK 18/2.6/10) can be toxic to small seedlings. A medium of equal parts good quality loam (disinfected to control weeds) and peat without any added fertilisers (or lime) is recommended for the initial potting-up of seedlings or rooted cuttings into tubes or small pots. This is particularly important for seedling Proteaceae since most species are very sensitive to transplanting stock and should be pricked out into individual containers at the first true leaf stage. They can then be held in pots and watered with a low strength liquid feed at regular intervals until potting-on into larger containers. A fertiliser-free mix should not be used for rainforest species like *G. robusta* since they would require a much higher nutrient supply than for proteas, waratahs and other species which are sensitive to even very low N and P levels. *G. rosmaranifolia* is an example of a strong growing species which could be potted directly into 'Plantabags' when cuttings are well rooted in tubes.

Proteoid Roots

Proteaceous shrubs have developed proteoid roots as an adaptaion to infertile soils in their native habitat. Nurserymen many consider these specialised structures to be mycorrhizal or pathogenic swellings and their significance has often been questioned. However these structures are scarce or totally absent with medium or even low levels of added fertilisers. Proteoid roots are not essential and satisfactory growth of container grown proteaceous plants is readily achieved without their presence.

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REFERENCES

ALCOCK, N. 1976 Boronias. Aust. Pl. 8 (66): 243, 280.

ALLAN, J.E. 1958 Atomic absorption spectrophotometry with special reference to the determination of magnesium. Analyst. 83: 466-71.

———— 1959 Determination of iron and manganese by atomic absorption. Spectrochim. Acta 10: 800-6.

ALVEY, N.G. 1955 Adapting John Innes Composts to grow Ericas. J.Roy. Hort.Soc. 80: 376-81.

ANDERSON, C.A. & LIDGES, P.Y. 1978 A comparison of three populations of *Eucalyptus obliqua* L' Herit. Growing on acid and calcareous soils in Southern Victoria. Aust. J. Bot. 26: 93-109.

ANON, 1971 Container grown shrubs. Luddington Expt. Hort.St. Lft. 3p.

ARMSTRONG, J. 1975 The family Rutaceae Aust. Pl. 8 (65): 195-99, 212-25.

ATTIWILL, P.M., 1964 Studies of soil fertility and plant nutrition in *Eucalyptus obliqua* (L' Herit). Ph.D Thesis. Univ. of Melbourne. 334p.

BATES, P.M. 1971 Composts for camellias. N.Z. Cam. Soc. Bull. VII (1): 25-8.

BAYLIS, G.T.S. 1967 Experiments on the ecological significance of phycomycetous mycorrhizas. New Phytol. 33: 231-43.

———— 1972 Fungi, phosphorus and the evolution of root systems. Search 3 (7): 257-9.

BEADLE, N.C.W. 1954 Soil phosphate and the delimitation of plant communities in eastern Australia I. Ecology 35: 370-75.

———— 1962 Soil phosphate and the delimitation of plant communities in eastern Australia II. *Ibid.* 43: 281-88.

———— 1966 Soil phosphate and its role in moulding segments of the Australian flora and vegetation, with special reference to xeromorphy and sclerophylly. *Ibid.* 47 (6): 992-1007.

———— 1968 Some aspects of the ecology and physiology of Australian xeromorphic plants. Aust. J. Sci. 30: 348-55.

BEARD, J.S. 1959 The origin of African Proteaceae. J. S. Afr. Bot. 25 (3): 231-5.

BONNER, J. 1947 Flower bud initiation and flower opening in the camellia. Proc. Am. Soc. Hort. Sci. 50: 401.

BONNER, J. & HONDA, S. 1950 Effect of varying pH on growth of camellia. Cam. Res. (So. Calif. Cam. Soc.): 25-7.

BOODLEY, J.W. & SHELDRAKE, R. 1963 Artificial soils for commercial plant growing. Cornell Ext. Bull. 1104 11p.

BOX, G.E.P. & HUNTER, J.S. 1957 Multifactor experimental designs for exploring response surfaces. Ann. Maths. Stat. 28: 195-241.

BOYD, D.A. & NEEDHAM, P. 1976 Factors governing the effective use of nitrogen. Span 19, 2, 68-70.

BRADHURST, P.J. 1954 The nutrient deficiencies of the Hawkesbury sandstone soils. M.Sc. Thesis 38p.

BROOKS, A.E. 1961 Australian native plants for cultivation. Lothian, Melbourne. 149p.

BRUNDELL, D.J. *et al.* 1975 (a) Development of loamless growing systems for glasshouse tomatoes. Levin glasshouse seminar. 1-8.

——————— 1975 (b) Propagating composts for glasshouse tomatoes. *Ibid.* 9-13.

BUNT, A.C. 1969. Peat sand substrates for plants grown in containers. Pl. Soil XXXI (1): 97-110.

——————— 1976 Modern potting compost. Allen & Unwin, London 227p.

BURBIDGE, N.T. 1960 The phytogeography of the Australian region. Aust. J. Bot. 8: 75-212.

CARTER, A.R. 1973 The nutrition of container grown plants. Proc. 8th Pershore Nurs. Ref. Course: 3-8.

COCHRANE, R.C. & MATKIN, O.A. 1967 Nutrient supply characteristics of slow release fertilizers. Pl. Prop. 12 (4): 2-10.

CONOVER, C.A. & POOLE, R.T. 1977 Effects of cultural practices on acclimatization of *Ficus benjamina* L. J. Amer. Soc. Hort. Sci. 102 (5): 529-31.

COOIL, B.J. *et al.* 1966 Relationships of phosphorus supply to growth, yield and leaf composition in Macadamia. Hawaii Ag. Expt. St. Tech. Bull. 66, 71p.

CREECH, J.L. 1958 Camellia species: their introduction and use 369-82 In Tourjé, E.C. Camellia culture. MacMillan, New York.

CROMER, R.N. *et al.* 1975 Eucalypt plantations in Australia - The potential for intensive production and utilisation. Appita 29 (3): 165-73.

DARLINGTON, P.J. 1965 Biogeography of the southern end of the world. Harvard University Press, Cambridge. 236p.

DAVIES, J. *et al.* 1973 Observations on the swollen roots of the Cyperaceae. New Phytol. 72: 167-74.

DICKEY, R.D. 1967 Factors affecting copper deficiency of container grown *Ligustrum japonicum.* Proc. Flor. St. Hort. Soc. 80: 409-15.

DICKEY, R.D. *et al.* 1961 Effect of nitrogen, phosphorous and potassium levels on growth and chemical composition of *Rhododendron indicum* 'Formosa' and *Viburnum suspensum. Ibid.* 74: 762-70.

DIGHT, R.J.W. 1977 Nutritional requirements of bedding plants. Expt. Hort. 29: 63-71.

ELIOVSON, S. 1967 Proteas for pleasure. Timmins, Cape Town. 228p.

ENGLER, A. 1889 Proteaceae. In A. Engler & K, Prantl (Eds), *Die natürlichen Pflanzenfamilien* 3: 119-56, Leipzig, Engelmann.

FAIRALL, A.R. 1970 West Australian native plants in cultivation. Permagon Press, N.S.W. 253p.

FISHER, K.J. 1969 Effects of nitrogen supply during propagation on flowering and fruiting of glasshouse tomatoes. J. Hort. Sci. 44: 407-11.

FROLICH, E. *et al.* 1966 Phosphorus toxicity in *Acacia obtusata* p. 170-1 In Wallace, A. Current topics in nutrition. Edwards Bros. Michigan.

FURUTA, T. 1976 Nitrogen fertilization of container-grown ornamentals. Am. Nurs. 142:14, 106-9.

FURUTA, T. *et al.* 1954 Influence of rate and analysis of fertilizer on the growth and survival of three camellia varieties. Am. Cam. Yrbk. 138-40.

FURUTA, T. 1969 Operations research and ornamental horticulture. Acta Hort. 15: 47-56.

GARDNER, C.A. 1959 The vegetation of Western Australia p. 274-82. In Biogeography and ecology in Australia W. Junk, The Hague.

GATES, C.T. 1972 Ecological response of the Australian native species *Acacia harpophylla* and *Atriplex nummularia* to soil salinity: effects on water content, leaf area, and transpiration rates. Aust. J. Bot. 20: 261-72.

GEHRKE, C.W. *et al.* 1973 Preliminary report on the Gehrke - Wall automated nitrogen methods for feeds. 1972 Technicon Int. Cong. New York (7): 25-32.

GOH, K.M. & HAYNES, R.J. 1977a Evaluation of potting media for commercial nursery production of container grown plants. II Effects of media, fertiliser N, nitrification and inhibitor on yield and N uptake of *Callistephus chinensis* (L.) Nees 'Pink Princess'. N.Z. J. Ag. Res. 20: 363-70.

——————————— 1977b Evaluation of potting media for commercial nursery production of container grown plants. III Effects of media, fertiliser nitrogen, and a nitrification inhibitor on soil nutrification and nitrogen recovery of *Callistephus chinensus* (L.) Nees 'Pink Princess'. *Ibid.* 20: 383-93.

GOH, K.M. & YOUNG, A.M. 1975 Effects of fertiliser N, and 2 chloro 6 - (trichloromethyl) - pyridoo (N - serye) on soil nitrification, yield and nitrogen uptake of 'Arawa' and 'Hilgendorf' wheats. *Ibid.* 18: 215-25.

GRAY, H. 1971 Light weight media for container growing of ericaceous plants. Int. Pl. Prop. Soc. Comb. Proc. 21: 416-9.

GROVES, R.H. 1964 Experimental studies on heath vegetation. Ph.D. Thesis, Univ. of Melbourne.

GRUNDON, N.J. 1972 Mineral nutrition of some Queensland heath plants. J. Ecol. 60: 171-81.

HALLIWELL, B. 1970 Proteas for glasshouse display. II Gdns. Chron. 8-10.

HARLEY, J.L. 1940 A study of the root system of the beech in woodland soils with special reference to mycorrhizal infection. J. Ecol., 28: 107-17.

——————— 1969 The biology of mycorrhiza. Plant science monography. 2nd Ed., Leonard Hill Bocks, London. 334p.

HARRISON, R.E. 1960 Handbook of trees and shrubs for the Southern Hemisphere. Reed. Wellington 347p.

HAYES, S.F. & SIMPSON, K. 1955 Micaceous materials in pot plant production. Gdns. Chron. 138: 210-12.

HAYNES, R.J. & GOH, K.M. 1977 Evaluation of potting media for commercial nursery production of container grown plants. II. N.Z.J. Ag. Res. 20: 371-81.

HEDDLE, E.M. & SPECHT, R.L. 1975 Dark Island Heath (Ninety-Mile Plain, South Australia). VIII The effect of fertilizers on composition and growth, 1950-1972 Aust. J. Bot. 23: 151-64.

HEWETT, H.M. 1975 The growing of Rutaceae. Aust. Pl. 8 (65): 202-6.

HIGGS, A.L. 1970 The effect of planting depth and fertilizer on survival and growth of *Grevillea* and *Leptospermum* rooted cuttings. Aust. Pl. (Dec) 6: 23-25.

HOCKINGS, F.D. 1970 Culture of grevillea. *Ibid.* 6 (Dec): 10-3.

——————— 1977 Banksias, propagation and culture. *Ibid.* 9 (71): 95-9, 101-3.

HODGE, M.W. 1970 Growing grevillea. *Ibid.* 6 (Dec): 2, 27-8, 43.

HOCKING, P.J. & THOMAS, M.B. 1974 Evolution of the Proteaceae and cultural implications. Ann. J. R.N.Z.I.H. (2): 18-25.

HOPPER, S.D. & MASLIN, B.R. 1978 Phytogeography of *Acacia* in Western Australia. Aust. J. Bot. 26: 63-78.

HUTCHINSON, J. 1967. The genera of flowering plants. Dicolyledons II Clarendon Press, Oxford, 659p.

ISHIGAKI, K. 1974 Comparison between ammonium - nitrogen and nitrate - nitrogen on the effect of tea plant growth. Jap. Ag. Res. Quart. 8 (2): 101-5.

——————— 1975 Influence of iron and manganese in the evaluation of ammonium and nitrate nitrogen on the tea plant. Study tea 48: 67-71.

ISHIGAKI, K. & HOSHINA, T. 1977 Contents of chemical component in tea plants with the amount of three manure elements by sand culture method. Tea Res. J. 45: 54-62.

JACKSON, M.L. 1958 Soil chemical analysis. Prentice Hall, New Jersey 498p.

JEFFREY, D.W. 1964 The formation of polyphosphate in *Banksia ornata*, an Australian heath plant. Aust. J. Biol. Sci. 17: 845-54.

―――――――― 1967 Phosphate nutrition of Australian heath plants I. The importance of proteoid roots in *Banksia* (Proteaceae). *Ibid.* 20 : 403-11.

JOHNSON, C.R. 1973 Symptomatology and analysis of nutrient deficiencies produced on flowering annual plants. Soil Sc. Pl. Analysis. 4 (3): 185-96.

JOHNSON, L.A.S., & BRIGGS, B.G. 1963 Evolution in the Proteaceae Aust. J. Bot. 11 (1): 21-61.

―――――――――――――――― 1974 On the Proteaceae - the evolution and classification of a southern family. Bot. J. Linn. Soc., 83-182.

JOHNSON, C.R. & MICHELINI, S. 1974 Effect of mycorrhizae on container grown acacia. Proc. Flor. St. Hort. Soc. 87: 520-21.

KAUL, O.M., *et al.* 1966a Nutrition studies of *Eucalyptus*. I Diagnosis of mineral deficiencies in *Eucalyptus* hybrid seedlings. Indian For. 92 (4): 264-8.

―――――――― 1966b Nutrition studies of *Eucalyptus* II. N, P, K requirements of *Eucalyptus* hybrid seedlings. *Ibid.* 92 (12): 772-8.

―――――――― 1968 Nutrition studies of *Eucalyptus* III. Diagnosis of mineral deficiencies in *Eucalyptus grandis* seedlings. *Ibid.* 94 (11): 831-4.

―――――――― 1970a Nutrition studies of *Eucalyptus* IV. Diagnosis of mineral deficiencies in *Eucalyptus globulus* seedlings. *Ibid.* 96 (6): 453-6.

―――――――― 1970b Nutrition studies of *Eucalyptus* V. Diagnosis of mineral deficiencies in *Eucalyptus citriodora* seedlings. *Ibid.* 96 (10): 787-90.

KENDER, W.J. & CHILDERS, N.F. 1959 Urea-Formaldehyde as a source of nitrogen for zinnia, New Jersey Ag. Expt. St. - Am. Soc. Hort. Sci. Vol. 74: 686-91.

KLOUGART, A. & BRAGGE OLSEN, O. 1969 Substratum for container grown plants. Acta Hort. 15: 34-6.

LAMB, D. 1977 Relationships between growth and foliar nutrient concentrations in *Eucalyptus deglupta*. Pl. Soil 47: 495-508.

LAMONT, B. 1972a The effect of soil nutrients on the production of proteoid roots by Hakea species. Aust. J. Bot. 20: 27-40.

―――――――― 1972b The morphology and anatomy of proteoid roots in the genus *Hakea*. *Ibid.* 20: 155-174.

―――――――― 1972c 'Proteoid' roots in the legume. Search 3 (3): 91-1.

―――――――― 1973 Proteaceae:ecology of the australian Proteaceae with implications for their cultivation. Aust. Pl. 7 (54): 47, 50-1, 54-5, 66-7.

LAMONT, B. & McComb, A.J. 1974 Soil microorganisms and the formation of proteoid roots. Aust. J. Bot. 22: 681-8.

LEVYNS, M.R. 1958 The phytogeography of members of Proteaceae in Africa. J.S. Afr. Bot. 24 (1): 1-9.

LIDGES, P.Y. 1974 Differention of some populations of *Eucalyptus viminalis* Labill. in relation to factors affecting seedling establishment. Aust. J. Bot. 22: 471-87.

LINDROSS, J. 1977 Gardening in Limestone areas. Aust. Pl. 9 (71): 120-1.

LONERAGAN, J.F. *et al.* 1966 Phosphorus toxicity in cereal crops. J. Aust. Inst. Agric. Sci. 32: 221-3.

McINTYRE, D.K. & PRYOR, L.D. 1974 Response of Flooded Gum in plantations, to added fertilisers. Aust. J. For. 37 (1): 15-23.

MALAJCZUK, N. *et al.* 1975 Phosphorus uptake and growth of mycorrhizal and uninfected seedlings of *Eucalyptus calophylla* R. Br. Aust. J. Bot., 23: 231-8.

MASSEY, D.M. & WINSOR, G.W. 1973 Crop responses to phosphate as influenced by soil pH. G.C.R.I. Ann. Rep. p.75.

METSON, A.J. 1956 Methods of chemical analysis for soil survey samples. Soil Bur. Bul. 12, 208p.

MIKOLA, P. *et al.* 1960 Vertical distribution of mycorrhizae in pine forests with spruce undergrowths. Ann. Bot. Fenn., 3: 406-9.

MOORE, C.W.E. 1961 Competition between *Eucalyptus melliodora* and *E. rossii* at varying levels of exchangeable calcium. Aust. J. Bot. 9: 92-7.

——————— 1966 Nutrition of *Grevillea robusta* Aust. Pl. 4: 39-47.

MOORE, C.W.E. & KERAITIS, K. 1966 Nitrition of *Grevillea robusta.* Aust. J. Bot. 14: 151-63.

——————————— 1971 The effect of nitrogen source on growth of Eucalypts in sand culture. *Ibid.* 19: 125-41.

MORGAN B.J. 1973 Trial of slow release nitrogen fertilisers in container grown nursery stock. Proc. 8th Pershore Nurs. Ref. Course: 20-25.

MORRISON, T.M. *et al.* 1960. Plant growth in expanded perlite. N.Z. J. Ag. Res. 3 (3): 592-7.

MOSSE, B. 1973 Plant growth responses to vesicular arbuscular mycorrhiza. IV. In soil given additional phosphate. New Phytol. 72: 127-36.

NORTH, C.P. & WALLACE, A. 1966. Planting mixtures, fertilisers and camellia culture. N.Z. Cam. Bull. IV (5): 20-31.

PARSONS, R.F. & SPECHT, R.L. 1967 Lime chlorosis and other factors affecting the distribution of *Eucalyptus* on coastal sands in Southern Australia. Aust. J. Bot. 15: 95-105.

PARVIN, P.E. *et al.* 1973 Proteas developmental research for a new cut flower corp. Hort. Sci. 8 (4): 299-303.

PATHMARANEE, N. 1974 Observations on proteoid roots. M.Sc. thesis Univ. of Sydney, 123p.

PEARSON, H.E. 1958 Irrigation and soil salinity p. 360-6. In Tourjé, E.C. Camellia culture, MacMillan, New York.

PENNINGSFELD, F. 1972 Macro and micro nutrient requirements of pot plants in peat. Acta Hort. (26): 81-102.

PETTIGREW, C.J. & WATSON, L. 1975 On the classification of Australian acacias. Aust. J. Bot. 23: 833-47.

POOLE, R.T. *et al.* 1968 Effect of soil media on container grown Hibiscus and Aralia. Proc. Flor. St. Hort. Soc. 81: 443-6.

——————— 1976 Chemical composition of good quality tropical foliage plants. *Ibid.* 89: 307-8.

PRAKASH, N. 1969 Some aspects of the life history of *Callistemon citrinus* (Curt.) Skeels. Aust. J. Bot. 17: 107-17.

PRYOR, L.D. 1975 The biology of eucalypts. Instit. Biol. Studies in Biol. 61. Canberra. 82p.

PURNELL, H.M. 1960 Studies in the family Proteaceae I. Anatomy and morphology of the roots of some Victorian species. Aust. J. Bot. 8: 38-50.

RAO, C.V. 1971 Proteaceae. Bot. Mono. (6) Coun. Sci. Ind. Res. New Delhi 208p.

ROCHFORD, T. & GORER R. 1961 The Rochford book of houseplants. Faber & Faber, London 230p..

ROURKE, J.P. 1972 Taxonomic studies on *Leucosperumum* R. Br. J. S. Agr. Bot., Suppl. 8: 190-4.

SCOTT, M. 1977 Methods of improving flower bud initiation in Camellias. Expt. Hort. 29: 80-93.

SEAGER, J.C.R. 1973 Effect of compost and rate of magnesium ammonium phosphate on growth of ficus and hedera. Acta Hort. (31): 173-80.

SELVENDRAN, R.R. & SELVENDRAN, S. 1973 Chemical changes in young tea plant (*Camellia sinensis* L.) Tissues following application of fertilizer nitrogen. Ann. Bot. 377: 453-61.

SLEUMER , H. 1954 Florae Malesianae presursores. VII. New Malaysian Flacourtiaceae. Blumea 7: 484 - 97.

SPECHT, R.L. 1963 Dark Island heath (Ninety-Mile Plain, South Australia) VII The effect of fertilizers on composition and growth, 1950-60. Aust. J. Bot. 11: 67-94.

————— 1969 A comparison of the sclerophyllous vegetation characteristic of mediterranean type climates in France, California and Southern Australia. *Ibid.* 17: 277-308.

————— 1972 The vegetation of South Australia. 2nd Ed. Adelaide, Govt. Printer. 50p.

SPECHT, R.L. & GROVES, R.H. 1966 A comparison of the phosphate nutrition of Australian heath plants and introduced economic plants. Aust. J. Bot. 14: 201-21.

van STADEN, J. 1967 Deficiencies of major nutrient elements in *Protea cynaroides* Linn., grown in sand culture. I. Foliar symptoms of deficiencies. J. S. Afr. Bot. 33: 59-64.

———————— 1968a Deficiencies of major nutrient elements in *Protea cynaroides* Linn. grown in sand culture. II effect on growth and chemical composition. *Ibid.* 34 (1): 27-30.

———————— 1968b The effect of trace element deficiencies on the Bot River protea (*Protea compacta*). *Ibid.* 34 (6): 397-400.

STEVENS, W.R. 1965 Growing South African Proteaceae in New Zealand. Bot. Soc. S. Afr. J. 51: 19-21.

STEWART, G.A. 1959 Some aspects of soil ecology. p. 303-14. In Biogeography and ecology in Australia. W. Junk, The Hague.

SUTTON, P.J. 1958 A review of literature relating to standard seed and potting composts. Ann. Rep. G.C.R.I. 69-78.

SYNGE, P.M. 1956 The Royal Horticultural Society dictionary of gardening (2nd. Ed) I, 512p.

THOMAS, M.B. 1974 Research on the nutrition of container - grown Proteaceae plants and other nursery stock. Int. Pl. Prop. Soc Comb. Proc. 24;313-25.

THOMAS, M.B. & SPURWAY M.I. 1975a Nitrogen levels in container mixes, Roy. N.Z. Instit. Hort. Ann. J. 3: 20-30.

———————————— 1975b Nitrogen levels in container mixes. Comm. Hort. 7 (5): 5, 7, 9 - 13, 17.

THRELKELD, J. 1962 The camellia book. Van Nostrand, New Jersey 204p.

TICKNOR, R.L. 1976 Calcium - a needed element. Quart. Bul. Am. Rhodo. Soc. 30(2):124.

TISDALE, S.L. & NELSON, W.L. 1970 Soil fertility and fertilizers. MacMillan, London. 694p.

TSURISHIMA, H. & DATE, N. 1971 Effects of N, P, K on the growth and flowering of some bedding plants. Jap. Soc. Hort. Sci. 40 (4): 71-9.

TSURISHIMA, H. & DATE, N. 1976 Effects of the three elements of fertilizer on nutritional element content and dry weight of some bedding plants and determination in the standard fertilisation. Bull. Tokyo Ag. Expt. St. 10; 20p.

VOGTS, M.M. 1954 Growing Proteaceae in the summer-rainfall area. Bot. Soc. S. Afr. J. 40: 18-21.

WATSON, D.P. & PARVIN, P.E. 1970 Culture of ornamental proteas. Hawaii Ag. Expt. St. Res. Bul. 147 24p.

WERNER, H.F. 1951 South African Proteaceae and their cultivation. Bot. Soc. S. Afr. J. 37: 34-9.

WILD, H. 1968 Phytogeography in South Central Africa. Kirkia 6: 197-222.

WILLE, D. 1968 Further investigations about the composition of peat substrate for young plants. Acta Hort. 8: 23-31.

WILLS, R.W. 1971 Delaware nurserymen briefed on camellia culture. Am. Nurs. 133: 16, 62-64.

WILLSON, D.C. 1975a Studies on the mineral nutrition of tea II Nitrogen Pl. Soil. 42: 501-16.

——————— 1975b Studies on the mineral nutrition of tea IV Potassium. *Ibid.* 43: 279-93.

——————— 1975c Studies on the mineral nutrition of tea. V Calcium. *Ibid.* 43: 295-307.

——————— 1975d Studies on the mineral nutrition of tea VI Magnesium. *Ibid.* 43: 309-16.

WILLSON, K.C. *et al.* 1975 Studies on the mineral nutrition of tea III Phosphate. *Ibid.* 43: 259-78.

WINSOR, G.W. 1973 Nutrition p. 35-42. In Kingham, H.G. The U.K. tomato manual. Grower Books, London.

WOOD, J.C. 1959 The phytogeography of Australia (in relation to radiation of Eucalyptus, Acacia, etc). p. 291-302. In Keats,A. biogeography and ecology in Australia. W.Junk, The Hague.

WOODS, M.J. *et al.* 1969 Developing standardised composts for tomatoes. Acta Hort: 181-185.

ZURBICKI, Z.J. & SHTRAUSSBERG, D.V. 1964 Foliar diagnosis of tea shrubs. Pl. Anal. Problems. IV: 392-7.

APPENDIX I

DETAILS OF EXPERIMENTS, PLANTS AND PLANT SPECIES

Chapter	Trial Number	Species	Treat.	Reps.	Total Plants
2	5	*Grevillea rosmarinifolia*	13	24	312
	27	*G. rosmarinifolia*	8	10	80
3	13	*Protea repens*	8	15	120
	26	*G. robusta*	8	10	80
	16	*Lycopersicon esculentum* 'Best of All'	14	15	210
	6	*Camellia japonica*	13	25	325
4	1	*Hakea laurina*	6	15	90
	2	*L. esculentum* 'Best of All'	6	20	120
	7	*L. esculentum* 'Best of All'	19	24	456
	17	*G. rosmarinifolia*	30	10	300
	20	*H. laurina*	30	10	300
5	11	*Boronia megastigma*	14	25	350
	34	*Choisya ternata*	10	9	90
	35	*Eucalyptus notabilis*	8	8	64
		E. viminalis	8	8	64
	42	*Acacia verticillata* 'Rewa'	12	7	84
6	12	*G. rosmarinifolia*	30	14	420
	50	*Callistemon citrinus*	30	10	300
	51	*H. laurina*	30	9	270
7	10	*Erica carnea* 'Springwood White'	13	25	325
	15	*E. carnea* 'Springwood White'	30	12	360
8	47	*Dianthus chinensis* 'Dwarf Fragrance'	27	10	270
	40	*Fatsia japonica*	14	10	140
	41	*Ficus elastica*	15	12	180
	39	*Tagetes patula* 'Sparky'	14	15	210
	46	*T. patula* 'Sparky'	30	14	420
9	22	*G. rosmarinifolia*	8	10	80
		P. scolymocephala	8	10	80
	23	*C. japonica*	8	10	80
		E. carnea 'Springwood White'	8	10	80
		H. laurina	8	10	80
	24	*Dryandra formosa*	4	10	40
		G. 'Olympic Flame'	4	10	40
	30	*G. robusta*	7	10	70

APPENDIX I contd.

Chapter	Trial Number	Species	Treat.	Reps.	Total Plants
	31	*G. robusta*	3	5	15
		G. rosmarinifolia	3	5	15
		Leucadendron adscendens	3	5	15
		Leucospermum candicans	3	5	15
		P. repens	3	5	15
		P. scolymocephala	3	5	15
	36	*E. nicholii*	6	10	60
		E. notabilis	4	10	40
10	18	*C. japonica*	10	10	100
		E. carnea 'Springwood White'	10	10	100
		G. rosmarinifolia	10	10	100
		H. laurina	10	10	100
	25	*P. scolymocephala*	36	7	252
	29	*Banksia spinulosa*	5	10	50
		D. formosa	5	10	50
		Telopea speciosissima	5	10	50
	32	*G. robusta*	3	5	15
		G. rosmarinifolia	3	5	15
		L. adscendens	3	5	15
		L. candicans	3	5	15
		P. repens	3	5	15
		P. scolymocephala	3	5	15

TOTAL 7,572 plts.

CLASSIFICATION - BOTANICAL, FUNCTION

Families	Genera	No. Spp.
ARALIACEAE	*Fatsia*	1
CARYOPHYLLACEAE	*Dianthus*	1
COMPOSITAE	*Lycopersicon*	1
	Tagetes	1
ERICACEAE	*Erica*	1
MIMOSACEAE	*Acacia*	1
MORACEAE	*Ficus*	1
MYRTACEAE	*Callistemon*	1
	Eucalyptus	3
PROTEACEAE (GREVILLEOIDEAE)	*Banksia*	1
	Dryandra	1
	Grevillea	3
	Hakea	1
	Telopea	1
(PROTEOIDEAE)	*Leucadendron*	1
	Leucospermum	1
	Protea	2
RUTACEAE	*Boronia*	1
	Choisya	1
THEACEAE	*Camellia*	1
10 FAMILIES	20 GENERA	25 SPECIES
	3 South African	
	8 Australian	
	3 Herbs	
	17 Woody	
	2 Pot Plants	
	1 Vegetable seedling	
	2 Bedding plants	
	16 Trees and shrubs	

APPENDIX II : PUBLISHED PAPERS

-eprinted from Ann. Jnl. Roy. N.Z. Inst. Hort. 1974 (2): 18-25.

Evolution of the Proteaceae and Cultural Implications

by
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INTRODUCTION

Although the family Proteaceae is relatively small, it embraces many beautiful trees and shrubs, e.g., the Australian Warratah *(Telopea speciosissima)*, the South African Sugar Bush *(Protea repens)*, and the Chilean Fire Bush *(Embothrium coccineum)*. A large number grow well in the warmer parts of New Zealand and are becoming increasingly popular.

Unfortunately, some of the most beautiful species of *Banksia, Protea Dryandra* etc. are either difficult to propagate or die soon after removal from the propagation bench. Consequently, many New Zealand nurserymen routinely suffer considerable set-backs and economic losses with proteaceous lines. A host of reasons has been advanced to explain the sudden demise of these plants, but few explanations are plausible or scientifically based. This is probably due to a lack of basic information on, and understanding of proteaceous distribution, ecology and physiology.

This article deals with the evolution, phytogeography and adaptive mechanisms of some Proteaceae and attempts to seek out factors which might shed light on causes of cultivation problems. Special reference is made to Australian heathland Proteaceae.

DISTRIBUTION AND EVOLUTION

The family Proteaceae consists of about 60 genera and 1300 species (Hutchinson, 1967). Present distribution is disjunct and virtually confined to the southern continents (Ramsay, 1963). Most Proteaceae are in Australia (approximately 35 genera and 800 species) and South Africa (approximately 14 genera and 380 species), with a few in Central and South America, tropical West Pacific, New Zealand and tropical Asia northwards to Japan (Hutchinson, 1967). Two Sub-families are recognized by Hutchinson (1967):–

1. Grevilleoideae – includes *Grevillea, Banksia, Dryandra* etc.
2. Persoonioideae – includes *Protea, Leucadendron* etc.

Persoonioideae (referred to by Rao (1971) as the Proteoideae) predominate in South Africa, while the Grevilleoideae are well represented in Australia (Ramsay, 1963). South Africa and Australia have no genera in common. Australia has several genera in the Persoonioideae, whilst South Africa has only one genus belonging to the Grevilleoideae. Although the Australian flora has a strong affinity with that of South America there is little evidence suggesting a similar relationship with the flora of Southern Africa (Burbidge, 1960). In the genus *Orites* for example, there are two species in South America and eight in Eastern Australia and Tasmania (Rao, 1971. The two New Zealand proteaceous genera *(Knightia* and *Persoonia)* are absent from South Africa and South America, with *Knightia* being confined to New Zealand and New Caledonia.

Proteaceae is an ancient family and its origin remains one of the major phylogenetic mysteries. Johnson and Briggs (1963) consider proto-Proteaceae existed before the Upper Cretaceous under tropical and sub-tropical rain forest conditions. By the end of the Upper Cretaceous, the Proteaceae had evolved and distribution was perhaps almost cosmopolitan, although evidence for this is rather inconclusive (Rao, 1971). Darlington (1965) believes the Proteaceae developed in the tropics and migrated southwards during a long period of widespread warm, moist conditions. Later, during a cold climate they became extinct in Antarctica and survived only in more northerly refugia, from where they spread southwards again with climatic improvement.

Burbidge (1960) discusses the evidence for an Antarctic origin and points out that the paucity of Proteaceae in New Zealand is unusual if they originated in Antarctica. Rao (1971) believes that Australia was the home of the Proteaceae which originated under mountainous rain forest conditions and later spread into the lowlands. Separation of ancestral stocks occured early during angiosperm development with subsequent independent speciation in the different land masses.

Proteaceae in Australia

It appears that many proteaceous genera arose in

Australia during a warm epoch, e.g. *Grevillea, Banksia, Dryandra* and *Persoonia* (Wood, 1959). Crocker (1959) states that by the Early Tertiary, Australia had a broad-leaved vegetation including proteaceous genera allied to *Hakea, Banksia* and *Persoonia* and concludes that these plants had sub-tropical affinities. Specht and Rayson (1957) give evidence that present-day sclerophyllous genera of Proteaceae e.g. *Banksia,* evolved under a warmer and moister climate than at present.

The Australian distribution of Proteaceae is interesting. They are only abundant in the relatively moist S.W., S., and E. coastal belts of Australia and are poorly represented in the arid regions. Seven of the genera in N.E. Queensland are endemic there. The S.W. province of Western Australia has five endemic genera (Gardner, 1959) while there are no species common with N.E. Queensland. Evidence suggests that many proteaceous genera were formerly much more widespread than at present, e.g. fossils of *Dryandra* spp. now confined to S.W. Western Australia have been found in Victoria (Johnson and Briggs, 1963).

Geological history shows that during the Cretaceous period the central part of Australia was flooded by the sea (Crocker and Wood, 1947), which almost reduced the continent to two large islands, one western, the other eastern. Consequently the flora of the central area was destroyed and the floras of the east and west became isolated. When the epicontinental sea receeded, the central part of Australia emerged as a flat, saline desert, uninhabitable to plants and has remained a formidable barrier to migration and inter-mixture of the Floras (Rao, 1971).

In addition, it appears that during the Miocene, earth movements occured in S.E. and S.W. Australia resulting in a great diversity of habitants and local climates (Wood, 1959). Browne (1945) provides evidence that during the Late Pleistocene, Australia's pluvial climate changed to an arid one with marked seasonality which essentially continues today. Australia also experiences periodic droughts which are very intense and may extend for months. These changes provided strong selective pressures and those proteaceous taxa which could adapt, spread from the rain forests, e.g. *Hakea, Banksia* etc., while others remained confined to them or became extinct. The selective pressures also led to speciation and subsequent endemism (Wood, 1959). This is especially so in the S.W. province of Western Australia, one of the world's richest floristic regions. About 75% of the species are endemic, a figure similar to that of the Cape Province flora of South Africa where there is strong endemism, particularly in the Proteaceae.

Burbidge (1960) regards the S.W. Province of Western Australia as the chief centre of proteaceous development in Australia, e.g. the three largest genera *Grevillea* (250 spp.), *Hakea* (140 spp.) and *Banksia* (40 spp.), have their main development there. However, Beadle (1962) points out that centres of greatest species abundance within a genus may not represent the centre of origin, but rather a local expression through edaphic and climatic control of a once plastic genus which migrated into an area capable of stimulating adaptive radiation.

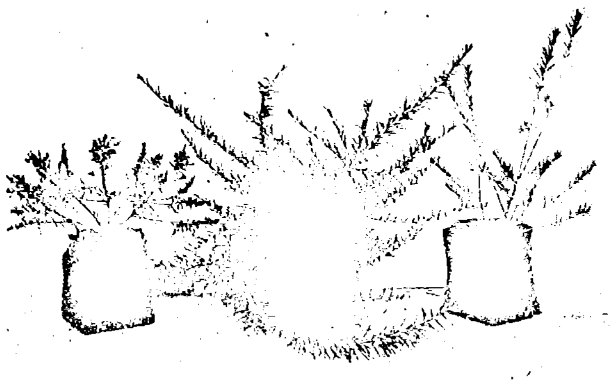
Proteaceae and the heathlands of Australia

Many of the cultivated Proteaceae come from the Australian heathlands. Typical heathland vegetation consists mostly of small stunted trees and shrubs, including *Banksia* spp., *Acacia* spp., *Eucalyptus* spp., *Epacris* spp. (the Australian heaths), *Casuarina* spp. etc. (Gardner, 1959; Specht, 1963). It invariably occurs on extremely impoverished acid to neutral sandy soils of the moist coastal areas of South West, South and Eastern Australia. The soils have very low available P, N, K and Ca, while Mo, S, Cu, Zn and B may also be extremely low (Specht, 1963; Stewart, 1959; Wood, 1959). P levels may be below 150 ppm in some soils of the S.W. Province of Western Australia (Beadle, 1962). Wood (1959) suggests it is the limiting P supply which determines the low N levels of these soils, since C, N, P and S occur in fairly constant proportions in soil organic matter.

Jeffrey (1967) considers that heathland Proteaceae have adapted to a low P and N requirement. Beadle (1954, 1968) also favours physiological adaptation and believes many of these plants have the ability to tolerate a low P turnover. Specht and Groves (1966) found that P is taken up in spring and stored as polyphosphate which is hydrolysed to orthophosphate and used in growth during summer. Wood (1959) showed that some species can pass into a static (but not dormant) condition when P and N levels are reduced, and remain in this state for up to two years. According to Wood (1959), the low fertility of the soils protects the heathland species against invasions by plants with a higher nutrient need.

Growth period

Lamont (1973) points out that the growth period of Australian Proteaceae may vary from five months, as in certain winter rainfall districts, to the whole year in others. It is noticeable that most of the South African Proteaceae inhabit the winter rainfall areas (Werner, 1951). Lamont (1973) mentions that proteaceous plants are unable to store water or tolerate large water deficits and therefore are not well adapted to drought. However,



Grevillea rosmarinifolia
showing N & P toxicity–N response N–deficiency

Levels of nutrient element supplied by fertilisers in peat/perlite mixes (left to right)

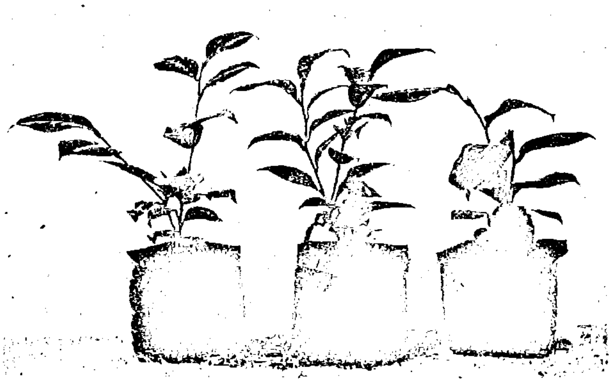
g/m^3 of potting mix

N	450	450	45
P	300	30	300
K	25	250	250

Left: *Hakea lavrina*
–showing toxicity at high NPK

Right: *Tomato 'Best of All'*
–showing response to high NPK and severe deficiency with no nutrients.

N	0	450	0	450
P	0	300	0	300
K	0	250	0	250

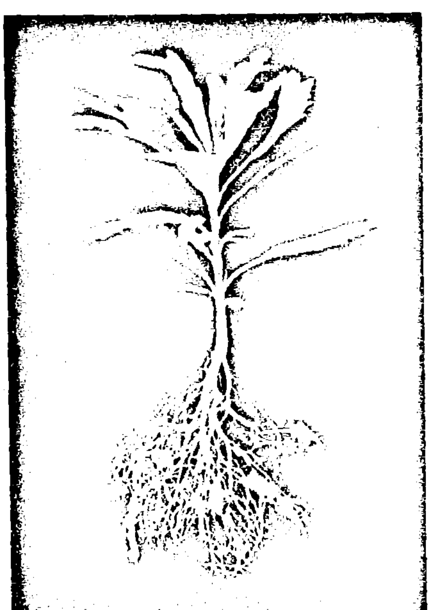


Camellia japonica responds in a different manner to the plants shown above and rather indifferently in the early stages of growth.

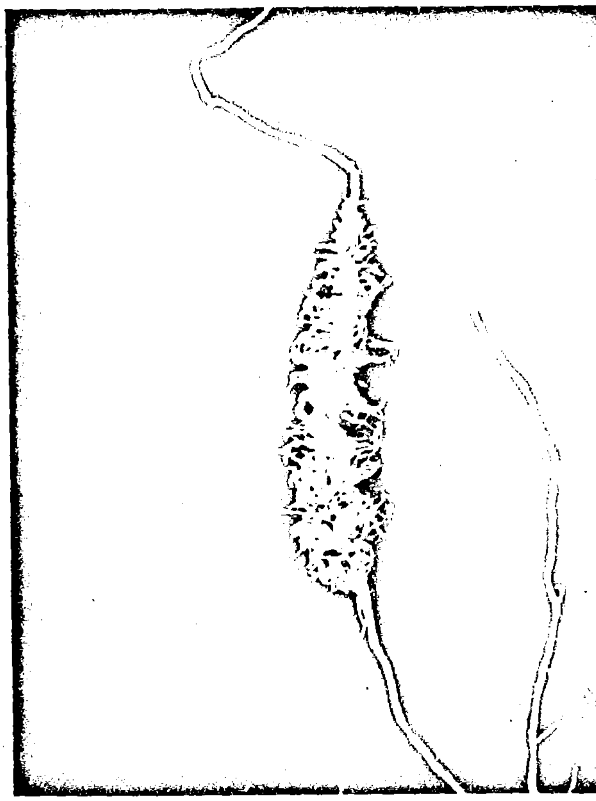
N	450	450	45
P	300	30	300
K	25	250	250

they are able to start or stop growth at any time during the year according to whether or not conditions are suitable.

Many proteaceous species are drought avoiders since they possess an extensive root system with deep lateral roots that penetrate into moist sub-soil (Specht and Rayson, 1957b). Wood (1959) points out that southern Australian heathland species, while flowering in spring show maximum growth during summer, the driest time of the year. For example, Specht and Rayson (1957a) found that *Banksia ornata* and B. *marginata* at Coonalpyn Downs, South Australia, only commenced growth when the mean temperature exceeded 18°C (November to April) which is out of phase with the wet season (winter) of this region. The growth of related heathland plants is also vigorous during summer in coastal Queensland where, although the temperature is high, it is accompanied by heavy rainfall. Thus, while heathland species from both these areas have their maximum growth in summer, those in Queensland are growing when rainfall is high and those in the south are exploiting soil water reserves with their deep root systems as rainfall is almost zero. Specht and Rayson (1957) suggest that the occurrence of Proteaceae on low fertility soils and the summer growth pattern of southern taxa are connected with the evolutionary history of heathland vegetation which apparently flourished during the Pleistocene period on widespread, infertile soils.



oteoid roots on *Telopea speciosissima*



Close up of proteoid roots.

Proteoid roots

Purnell (1960) defines a proteoid root as a dense cluster of rootlets of limited growth along a lateral root, and several others have described their development. They appear to last only one season and by the end of summer are dry and shrivelled (Purnell, 1960) although the parent roots last indefinitely (Lamont, 1972a). Lamont (1972a) found them to be physiologically active for two to three months and they seem to be produced by the youngest roots of the root system. Purnell (1960) and Lamont (1972b) have described their anatomical features.

Proteoid roots have been found on a wide range of Australian Proteaceae, Purnell, 1960; Jeffrey, 1964 and 1967; Rao, 1971; Lamont, 1972 a and b), but they have also been observed on South African genera, e.g. *Protea* spp. in work at Lincoln College.

Several studies have been made to determine the nutritional significance of proteoid roots. Jeffrey (1967) working with *Banksia ornata* heathland, found a discrete zone 2.0-3.5 cm. thick in the soil profile composed of a mass of proteoid roots. The zone was not more than 5 cm deep and proteoid roots penetrated into the litter layer.

Symptoms of phosphate toxicity on *Grevillea rosmarinfolia*. The plant on the right appears to have recovered from an initial period of mild toxicity.

Levels of nutrient element supplied by fertilisers in peat/perlite mixes (left to right)

	g/m^3 *of potting mix*			
N	45	450	45	45
P	30	30	300	30
K	25	25	25	250

Protea repens

Left	Good growth under vey low nutrient levels
Centre Left	Nitrogen toxicity
Centre Right	Phosphorus toxity
Right	Good growth and no adverse effect from high potassium levels.

Under some conditions the proteoid root carpet may be almost continuous. Jeffrey (1967) considers it may act as a trapping surface for nutrients from a number of sources including cyclic salts and litter decomposition. In glasshouse culture they have been observed to develop on the top of a moist bench.

Beadle (1968) using *Hakea dactyloides,* found consistent development of proteoid roots on plants grown under low P, but not on plants grown under high P. Lamont (1972a) found that proteoid roots responded to lower levels of N and P than non-proteoid roots, and concluded nutrient concentration, especially N and P, largely determines the relative contribution of proteoid roots to the plant. Jeffrey (1967) found that they were very effective at absorbing P and considered this was due to a large surface area.

Rao (1971) states that proteoid roots are directly involved in N and P uptake under natural conditions, and they do not appear to be mycorrhizal. Lamont (1972a) found no evidence of endophytic fungi or bacteria despite extensive investigations. The roots are neither modified N fixing nodules nor a reaction to invasion by pathogens, and Lamont (1972a) concludes that proteoid roots are normal components of the root system of many Proteaceae.

The development of proteoid roots in the Proteaceae appears to be a remarkable adaptation to cope with low fertility soils. They probably evolved on ancestral Proteaceae when Australia and S. Africa were closer together, since it is unlikely that they would have arisen independently in the different genera. It seems that even in the period when early angiosperms flourished, some Proteaceae were adapted to low fertility soils primarily determined by low available P (Beadle 1962).

Proteoid roots are probably of little importance in nursery or home garden situations despite the great

:ological significance of this adaptation, because the lants are able to absorb adequate nutrients through their on-proteoid root system. In fact, Lamont (1972a) ound that high levels of soil organic matter and nitrogen :nd to decrease the ratio of proteoid roots to non-roteoid roots.

Adaptions of the Proteaceae

As pointed out above, many of the S. African and Australian Proteaceae have evolved proteoid roots as a means of enhancing nutrient uptake, and certainly in Australia, most members of associated heathland families have specialised means of increasing their nutrition e.g. the *Epacridaceae (Epacris etc.)* use endophytic mycorrhizae, the *Fabaceae* and *Mimosaceae* have N. fixing nodules and the *Casuarinaceae* (a non-legume family) also have N. fixing nodules. Further, most of the sclerophyllous heathland species are sensitive to changes in their micro-habitats (Woods 1959). For example Pryor (1959) points out that the intricate distribution pattern of heathland *Eucalyptus spp.* accords with microhabitat changes. Gardner (1959) states that several heathland Proteaceae show marked specificity or adaptation to environmental parameters, e.g. climate, soil type and fertility, altitude, proximity to the sea, water and temperature regimes etc. and appear to have a very limited ability to tolerate changes. It is proposed that the high degree of adaptation and intolerance to change shown by the Proteaceae has a profound effect on the nutritional requirements and responses of these plants under cultivation.

Nutrition

Beadle (1962) found no improvement in the growth of *Hakea dactyloides* as soil P increased. Specht (1963) observed that seed germination of *Banksia ornata* was not improved by increased fertility. In addition, seedlings were unable to withstand the shock effects of some fertilisers. Moore (1966), and Moore and Keraitis (1966) using *Grevillea robusta* seedlings found that development of deficiency symptoms for P and N depended both on the level of each nutrient and also the balance of the two. Available soil P was considered to be the most important factor. However, *G.robusta* seedlings responded to increasing levels of N especially at high levels of K, and vice vera i.e. there was a significant interaction between N and K in the growth of *G.robusta.*

Probably the most important work so far is that of Grundon (1972) who studied the nutrition of Queensland heath vegetation. He found that Proteaceae were suppressed by high P levels. Grundon (1972) noted P Toxicity at low N and sometimes K levels and considers that the Proteaceae have a high capacity for using very low levels of available P since the metabolism of these heathland species is adapted to use P more efficiently than other species. He concludes that high P levels are likely to be toxic or to suppress the heathland Proteaceae.

Work at Lincoln College has confirmed the marked sensitivity of several Proteacease e.g. *Protea sp., Hakea laurina* and to a lesser extent *Grevillea rosmarinifolia* to high levels of P, especially when the plants are small. Apparently the sensitivity of *G. rosmarinifolia* declines as the plants become larger. In addition, *G. rosmarinifolia* seems to respond quite well to increased N in the compost.

Jeffrey (1964) has shown that many Proteaceae are calcifuges, and because they are adapted to make maximum growth at low Ca. levels, they are unable to avoid excessive Ca. uptake, when grown in soils with high levels of Ca resulting in toxicity. A similar situation is thought to occur with P. Consequently, the Proteaceae are very prone to P toxicity. Ca levels may also be critical, not only through direct toxicity but also indirectly via external and internal pH effects on the plant's nutrition. In the past, many proteaceous losses have been attributed to pathogenic fungi, particularly *Phytophthora spp.*, causing root rots and a blackening and die-back of shoot tips (Salinger, 1964). Hewett (1972) believes that *Phytophtora cinnamomi* is perhaps the greatest destroyer of Proteaceae. However, symptoms of P toxicity in Proteaceae have been observed at Lincoln College as a blackening of shoot tips followed by rapid death. Therefore, it is quite probable that many deaths attributed to *Phytophthora* spp. are in fact due to P toxicity since many nurserymen use composts which are high in nutrients, especially N, P and K.

It is also important to remember that the degree of toxicity would vary with:–

1. Plant size – generally large plants would be more tolerant than small ones.
2. The species – e.g. *Grevillea rosmarinifolia* appears to be more tolerant of P and N fertilizer than *Hakea laurina,* which is in turn slightly more tolerant than *Protea spp.*
3. The type of potting compost – its drainage, aeration structure and texture etc.
4. The aerial environment e.g. temperature regime, relative humidity, air circulation etc.

There are several other adaptive and ecological factors which seem to be important when Proteaceae are cultivated. A free draining acid soil or compost is desirable (Salinger, 1963). This is to be expected since most of the cultivated Proteaceae come from acid, sandy, well-drained soils.

Also a warm coastal or frost-free hilly situation seems to be beneficial as most Proteaceae appear to need good air circulation and are intolerant of frosts, correlating with their predominately coastal or steepland distribution. For example, Eliovsen (1957) states that *Leucadendron argenteum* does best in frost-free coastal areas where there is a sea mist as on the Cape Peninsula.

Watering may be critical since many of the Proteaceae are xerophiles (Willis 1966) and come from areas with a marked seasonal drought.

In addition, some species show little growth in spring and should not be watered in the same way as many other plants which are at their maximum growth. The quality of the irrigation water may be another important factor. Eliovsen (1957) considers that basal watering is better than overhead sprinkling and warns against sprinkling the leaves, especially on dull cloudy days when evaporation is low. Some form of trickle irrigation may be beneficial here. Heavy summer rain and warm humid conditions appear to be injurious to many S. African species (Eliovsen 1957).

Propagation by seed may present problems since the seed in some of the species does not mature until about a year after flowering (Salinger 1964). Seeds may be abortive in some countries because there are no suitable pollinators present and often the percentage of fertile seeds (as in *Protea* spp.) may be very low indeed (Stevens 1965).

Conclusions

The Proteaceae are an extremely old Angiosperm family which probably arose in the distant past in the tropical regions from where they became widespread. They migrated south and some adapted to the different climates encountered. Early in their development an ancestral line became adapted to infertile soils by developing proteoid roots and physiological tolerance of low nutrient levels. During the intervening geological periods up to the present, other adaptive mechanisms evolved. Concurrently, selection pressures and continental drift led to the extinction of many groups and resulted in the present day disjunct distribution of some genera in the southern continents. In particular the Proteaceae are intimately associated with the heathland areas of S. Africa and Australia where conditions stimulating intense adaptive radiation once occurred. Both these areas are extremely low in P and N and survival of the vegetation is primarily determined by the ability of the plants to withstand long periods of mineral starvation combined with drought. Proteoid roots enhance their ability to absorb nutrients and are an ecological advantage to this essentially successional group of plants.

It is not surprising that the complex adaptation of many Proteaceae to their habitats makes them intolerant of changes in environmental parameters, e.g. soil fertility, pH etc. This is most important when these species are grown in nurseries and gardens, often in environments to which they are unadapted and which, in many cases, they cannot tolerate. Often nurserymen have failed to realise this and explain the demise of these species in vague terms of disease or failure to form proteoid roots. However, it is more likely to be the high nutrient levels, especially P, of their potting mixes that is causing the plants to die since many of the Proteaceae are intolerant of such abundant nutrients. The growers are killing these plants with kindness!

In addition, other adaptational features of the Proteaceae e.g. specific pollinaters, intolerance of alkalinity, the need for good air circulation (possibly an adaptation to windy sites) etc. may be the cause of problems under cultivation.

Finally, the following pointers for nursery culture, based on research at Lincoln College and in conjunction with the factors already discussed are listed:–

1. **Phosphate Fertilisers**
   Only very low levels are required. Medium levels 300 P/cu.m (3lb superphosphate/cu.yd) will rapidly kill Proteas and cause foliar burn on Grevilleas in light weight mixes. High P levels have probably been the greatest single problem in the nursery culture of proteaceous plants. Young plants are particularly sensitive.
2. **Nitrogen Fertilisers**
   Low to medium levels of nitrogen are required. Grevilleas show a marked response to nitrogen fertilisers although Proteas can be severely burnt back by medium to high levels.
3. **Potassium Fertilisers**
   No potassium toxicity has been observed; however only low levels appear necessary.
4. **Other Aspects of Nutrition**
   An acid to neutral medium is best. Normal liming rates (6kg/cu.m) appear quite satisfactory for many Proteaceae using a soil-less container mix such as 50% peat and 50% perlite. No foliar chlorosis has yet been observed in trials at Lincoln College, because adequate levels of chelated iron have been included in the mixes. Young plants are particularly sensitive to fertilisers and may be killed by even very low levels of P and possibly N in the mix. A container mix consisting of 25% soil and 75% perlite and no fertilisers or lime has proved very satisfactory. Soil does not appear

to be essential in potting mixes and it is unnecessary to supply micro-organisms to form mycorrhiza. Current research (Baylis 1972, Lamont 1972, a) does not support the view held by some nurserymen and workers that Proteoid roots are the result of a mycorrhizal association.

5. General Culture

Proteaceous plants should be grown in an open, well-drained mix. As already discussed they are fairly drought resistant. However, young plants under glasshouse conditions will need regular watering. Older plants must also not be allowed to get too dry. Caution must be used with watering since some species, particularly Protea spp., can be killed if water lies on the leaves especially if this is coupled with stagnant or warm, humid air conditions. Fans for internal air circulation in glasshouses can be very useful.

REFERENCES

BAYLIS, G. T. S. 1972. Fungi, phosphorus and the evolution of root systems. Search 3(7) : 257-9.

BEADLE, N. C. W. 1954. Soil phosphate and the delimitation of plant communities in Eastern Australia. Ecology 35 : 370-375

——— 1962. Soil phosphate and the delimitation of plant communities in E. Australia. II. Ecology 43 : 281-288.

——— 1968. Some aspects of the ecology and physiology of Australian xeromorphic plants. Aust. J. Sci. 30 : 348-355.

BROWNE, N. R. 1945. An attempted post-tertiary chronology for Australia. Pres. Add. Linn. Soc. N.S.W. 70.

BURBRIDGE, N. T. 1960. The phytogeography of the Australian region Aust. J. Bot. 8 : 75-211.

CROCKER, R. L. 1959. Past climatic fluctuations and their influence upon Australian vegetation. *In* Biogeography and ecology in Australia. p. 283-290. W. Junk, The Hague.

——— & WOOD, J. G. 1947. Some historical influences on the development of the South Australian vegetation communities. Trans. Roy. Soc. S. Aust. 71 : 91-136.

DARLINGTON, P. J. 1965. Biogeography of the southern end of the world. Harvard University Press, Cambridge, Mass. 236 p.

ELIOVSEN, S. 1957. South African flora for the garden. 2d Ed. Trimmins, Cape Town. 306p.

GARDNER, C. A. 1959. The vegetation of Western Australia. *In* Biogeography and ecology in Australia. p. 274-282. W. Junk, The Hague.

GRUNDON, N. J. 1972. Mineral nutrition of some Queensland heath plants. J. Ecol. 60 : 171-181.

HEWETT, H. M. 1972. A discussion of plant collapse. Australian plants. 6 : 359-366.

HUTCHINSON, J. 1967. The genera of flowering plants. Dicotyledones II Clarendon Press, Oxford. 659p.

JEFFREY, D. W. 1964. The formation of polyphosphate in *Banksia ornata*, an Australian heath plant. Aust. J. Biol. Sci. 17 : 845-854.

JEFFREY, D. W. 1967. Phosphate nutrition of Australian heath plants I. The importance of proteoid roots in *Banksia (Proteaceae)*. Aust. J. Bot. 15.: 403-411.

JOHNSON, L. A. S. & BRIGGS, B. G. 1963. Evolution in the Proteaceae. Aust. J. Bot. 11 : 21-61.

LAMONT, B. 1972. (a) The effect of soil nutrients on the production of proteoid roots by Hakea species. Aust. J. Bot. 20 : 27-40.

——— 1972. (b) The morphology and anatomy of proteoid roots in the genus *Hakea*. Aust. J. Bot. 20 : 155-174.

——— 1973. The proteaceae. The ecology of the Australian proteaceae with implications for their cultivation. Aust. P. 7(54) : 47, 50-51, 54-55, 66-67.

MOORE, C. W. E. 1966. Nutrition of *Grevillea robusta*. Australian Plants 4 : 39-47.

MOORE, C. W. E. & KERCUTIS, K. 1966. Nutrition of *Grevillea robusta*. Aust. J. Bot. 14 : 151-163.

PRYOR, L. D. 1959. Species distribution and association in *Eucalyptus*. *In* Biogeography and ecology in Australia. p461-471. W. Junk, The Hague.

PRUNELL, H. M. 1960. Studies in the family Proteaceae I. Anatomy and morphology of the roots of some Victorian species. Aust. J. Bot. 8 : 38-50.

RAMSAY, H. P. 1963. Chromosome number in the Proteaceae. Aust. J. Bot. 11 : 1-20.

RAO, V. C. 1971. Proteaceae. Council of Scientific and Industrial Research, New Delhi, 208p.

SALINGER, J. P. 1964. Proteas in the flower garden. N.Z. J. of Ag. 10 : 443-451.

SPECHT, R. L. 1963. Dark Island heath (Ninety-mile Plain, South Australian) VI. The effect of fertiliser on competition and growth 1950-60. Aust. J. Bot. 11 : 67-94.

SPECHT, R. L. & GROVES, R. H. 1966. A comparison of the phosphate nutrition of Australian heath plants and introduced economic plants. Aust. J. Bot.14 : 201-221.

SPECHT, R. L. & P. RAYSON. 1957. (a) Dark Island heath (Ninety-mile Plain, South Australia) I. Definition of the ecosystem. Aust. J. Bot. 5 : 52-85.

——— 1957. (b) Dark Island Heath (Ninety-miles Plain, South Australia)III. Root systems. Aust. J. Bot. 5 : 103-14.

STEVENS, W. R. 1965. Growing South African Proteaceae in New Zealand. Bot. Soc. S. Afri. J. 51 : 19-21.

STEWART, G. A. 1959. Some aspects of soil ecology. *In* Biogeography and ecology in Australia. p.303-314. W. Junk, The Hague.

WERNER, H. F. 1951. South African Proteaceae and their cultivation. Bot. Soc. S. Afr. J. 37 : 34-39.

WILLIS, J. C. 1966. A dictionary of the flowering plants and ferns. 7th ed. University Press, Cambridge, 1214p.

WOOD, J. C. 1959. The phytogeography of Australia (in relation of *Eucalyptus, Acacia* etc.) *In* Biogeography and ecology in Australia. p. 291-302. W. Junk, The Hague.

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RESEARCH ON THE NUTRITION OF CONTAINER-GROWN PROTEACEAE PLANTS AND OTHER NURSERY STOCK

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Abstract. The nutrition of six species of plants was examined using peat: perlite (1:1) mixes and slow-release fertilisers in factorial experiments. Most plants responded strongly to nitrogen while there was little response to phosphorus. Medium phosphorus levels proved fatal for *Protea repens* and depressed the growth of *Grevillea rosmarinifolia* particularly when accompanied by high nitrogen. Tomatoes responded to very much higher fertiliser levels than proteaceoks and other shrubs and there was a very strong N x K interaction with tomatoes even though they were grown in winter.

REVIEW OF LITERATURE

Gardeners and nurserymen alike have often found plants in the Proteaceae difficult to grow unless certain requirements are met. Plants may die early and can be particularly difficult to grow in containers; a comparison of their growth response with other nursery plants like camellia, erica and tomato will give an insight into their relative nutritional requirements.

Various reasons have been put forward for losses of proteaceous plants including disease and faults with general culture. Hewett (18) states that attack by the fungus *Phytophthora* *cinnamomi* is perhaps the greatest destroyer of plants in the Proteaceae and that it is spread through infected nursery plants or soil.

Many proteaceous plants prefer acid soils and high levels of calcium may result in toxicity (24). Higgs (19) found that the planting depth in containers is important and that the survival of *Grevillea rosmarinifolia* rooted cuttings was severely reduced by planting at 5 cm. depth rather than 1 cm. Plant size and the aerial environment such as temperature regime, relative humidity, and air circulation may also influence plant losses in nurseries.

Nutrition and fertiliser problems are probably the greatest single cause of difficulties in the nursery culture of the Proteaceae. Many of the cultivated Proteaceae come from the Australian Heathlands and the slopes of the coastal mountains of South Africa. The growth of proteaceous plants in their native habitat gives a good indication of their cultural requirements. The distribution and evolution along with cultural implications was reviewed by Hocking and Thomas (2). Soil fertility is a key aspect in the distribution of proteaceous plants in Australia. The plants grow in moist coastal areas on extremely impoverished acid to neutral soils which are very low in P,N,K and Ca, and many trace elements (34, 37, 41). Phosphate has been shown to be the key factor since it influences organic matter levels and protects the health-land species against invasion by competitive plants which need more fertile soils than the Proteaceae (41). Proteaceous plants have adapted to a low P and N requirement (5, 7, 24, 33); for example, some can take up phosphate in the spring and store it until it is required in the growing season (35). Proteoid roots are a further adaptation and are dense clusters of rootlets of limited growth along a lateral root (32) and have been found on a wide range or proteaceous species from Australia (23, 24, 25, 26, 32) and South African species (2). Proteoid roots do not appear to be mycorrhizal (4, 33) and are primarily an adaptation to low fertility soils (6).

Hodge (22) reported that fertilisers high in phosphate have been responsible for the death of many grevilleas. Iron chelates and sulphate of ammonia were recommended to correct chlorosis. Higgs (19) in nursery container trials found that *Grevillea rosmarinifolia* developed chlorotic foliage with full strength fertiliser treatments at normal depths of planting. He found that as time passed growth was inhibited and the lack of vigour became noticeable compared with the healthy appearance of plants grown in the half strength and nil fertiliser treatments. Hockings (21) states that, in general, grevilleas prefer a soil with definite acid reaction but that there are two quite well known exceptions, namely *Grevillea robusta* and *G. striata*, both of which can thrive in alkaline soils. *Grevillea robusta* grown in containers will respond to increasing levels of nitrogen especially at high levels of potassium (27, 28).

Van Staden (38) and Parvin, et al (31) observed and described deficiency symptoms in proteas and found that nitrogen deficiency in *Protea cynaroides* will reduce the dry weight yield of leaves and roots, while potassium and calcium deficiencies will give a general reduction of growth. Low levels of N, K, Ca, Fe in the potting mix will reduce the level of iron in the plant and lead to foliar chlorosis (38). Vogts (39) warned against the use of manure for proteas while Stevens (36), in contrast, recommended liberal applications. Watson and Parvin (40) state that the premature death of proteas is common at any age and most common at the end of a dry season or after over-watering and they attribute this to a serious outbreak of soil-borne fungi. They point out that observations indicate that proteas respond to standard fertiliser programmes.

Camellias respond to supplementary nitrogen feeding when grown in John Innes and U.C. mixes (3). Nitrogen is the major nutrient that needs to be added to sustain growth of camellias (8, 13, 14, 29) while phosphorus, potassium and sulphur are needed in lesser amounts (8, 29). An N. P. K. ratio of 3:2:3 appeared to give optimum growth (13, 14).

Gray (16) reports that light-weight soil-less media are of value for the production of container-grown ericaceous plants and that these plants should be induced to make growth early in the season. Alvey (1) recommended that "flowers of sulphur" should be substituted for chalk in John Innes mixes in order to improve growth and overcome chlorosis which occurs due to lime-induced iron deficiency. Potting mix and feeding trials on *Erica carnea* 'Springwood White' in England showed that this plant established poorly in loamless mixes, appeared chlorotic and was a poorer quality as fertiliser rates increased (2, 11). It was found that these plants grew better in JIP II and were much larger than those in loamless mixes and concluded that a low rate of feeding is needed with loamless mixes.

High fertiliser levels can reduce the growth of container grown tomatoes in winter when light levels are low in Europe (10, 42). This was most severe where high rates of N and Ca were combined with low rates of P (10). It was also found that the peat/sand mixture was deficient in available nitrogen but that increased N levels were more likely to reduce growth in peat/sand in winter than when a loam mix is used. In summer the position was reversed and there was a positive response to each increment of N in the peat-sand mix and growth was significantly better than the growth of tomatoes grown in a loam compost.

MATERIALS AND METHODS

This article reports on the first six of a series of separate trials carred out at various times with different nursery plants in containers. The intention was to standardize materials and methods as much as possible and follow New Zealand commercial practice while still retaining an adequate level of scientific "technique." All trials were based on a N. P. K. 2^3 factorial using randomised blocks and analysed for analysis of variance and Duncan's Test. The physical part of the mix was peat-lite mix B (9) which has the advantage of being relatively inert and chemically uniform (30) and is used by commercial nurserymen. Slow release fertilisers are used where possible.

All trials were based on the following:

Physical Ingredients: 50% Dipton sphagnum peat; 50% horticultural grade perlite (Perloam)

Chemical Ingredients:

	Fertiliser			Nutrients g/m³		
	kg/m³	lb/yd³		N	P	K
A base of:-	0.25	0.42	Osmocote NPK 18/ 2.6/10	45	30	25
plus:-	4.5	6.74	dolomite lime			
	1.5	2.53	carbonate of lime			
	0.075	0.136	iron chelate (Sequestrene Na/Fe)			
	0.150	0.253	Trace element mix (Sporumix) - approx. 10% Mg. 1% Cu. 1% Bo. 5% Mn. 0.1% Mo)			

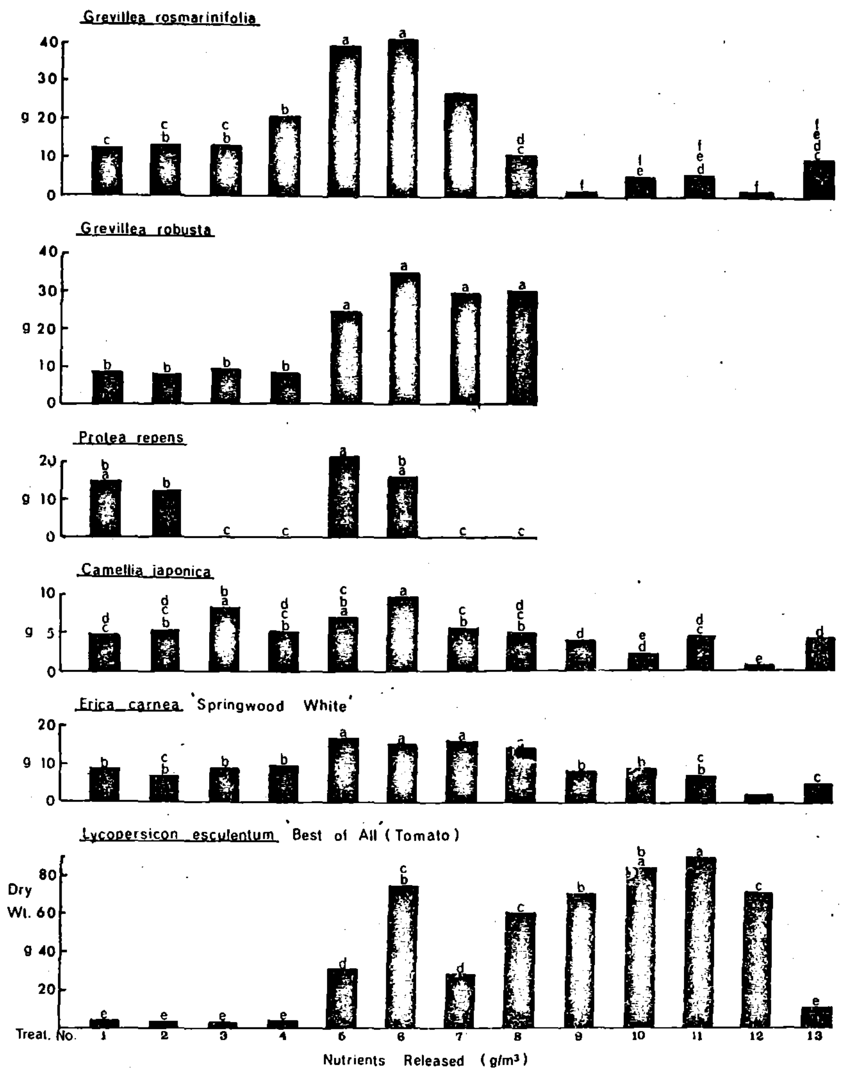
(Note the above 5 ingredients constitutes treatment 1 in all 6 trials)

Further treatments were made up by adding some or all of three fertilisers; for example, with treatment 8 in all the trials:

	Fertiliser		Nutrients g/m³		
	kg/m³	lb/yd³	N	P	K
Osmocote 26%N	1.558	2.63	405		
Superphosphate 9%P	3.000	5.06		270	
Sulphate of potash 39%K	0.577	0.97			225
plus base fertilisers			45	30	25
Total NPK nutrients			450 :	300	: 250

No soil disinfection was carried out and black plastic PB5 (3 litres approx. capacity) planter bags were used in each case. Yields were assessed by cutting off the above ground parts of the plant at soil level and then obtaining the oven-dry weight of each foliage sample. Statistical analyses including F Test and analysis of variance; factor interactions and Duncan's test on the data were obtained by computer analysis. Visual ratings were carried out during the running of the trials and statistically analysed in the same manner as dry weights (Results of ratings are not shown).

The 13 treatments (Fig. 1) were the same in each trial, except that



Treat. No.	1	2	3	4	5	6	7	8	9	10	11	12	13
N	45	45	45	45	450	450	450	450	900	450	450	900	0
P	30	30	300	300	30	30	300	300	300	600	300	600	0
K	25	250	25	250	25	250	25	250	250	250	500	500	0

Figure 1. The dry weight growth response of the various species to different levels of N. P. and K. (Levels of significance can only be compared within one species — with small letters in common above the columns there is no significant difference at the 5% level using Duncan's test).

with *Grevillea robusta* and *Protea repens*, the last 5 treatments were omitted. The trials were based on two levels of each of N. P. & K.; i.e. at 2^3 factorial plus five additional treatments (except *Protea repens* and *Grevillea robusta* expts.). All were carried out in a heated glasshouse equipped with automatic fan ventilation.

Table 1: Details of Individual Trials

Plant species lifted	No. of treat-ments	Reps. (plants per treat.)	plants grown from	Date Bagged	Date Lifted
Grevillea rosmarinifolia	13	24	cuttings	22.9.72	2.5.73
Grevillea robusta	8	10	seed	14.12.73	6.8.74
Protea repens	8	15	cuttings	26.3.73	10.6.74
Camellia japonica	13	25	seed	25.9.72	25.9.73
Erica carnea 'Springwood White'	13	25	cuttings	27.12.72	24.10.73
Lycoperscion esculentum 'Best of All' (Tomato)	13	15	seed	14.6.73	24.8.73

RESULTS

Grevillea rosmarinifolia Experiments: Visual ratings during the early stages (data not given), showed that mild toxicity occurred in varying amounts in treatments 7-12. Analysis of the interactions (not shown) revealed that there was a significant N x P interaction; i.e. these two elements acted to depress growth more than if either one was at high levels on its own.

The dry weights (Fig. 1) indicated the prominent influence of nitrogen in the growth response. Additional potassium was not beneficial while additional phosphate significantly depressed yields

Figure 3 is designed to illustrate the interactions between any two elements. Relative dry weight figures are plotted on a square base and shown by the vertical height above each of the four points. In the N.K. figure for *Grevillea rosmarinifolia*, the lowest point of the box design is low N + low K and the greatest yield is at N + low K. An alternative way to show this second diagram would be as vertical columns representing the yield in g of dry weight (Fig. 2):

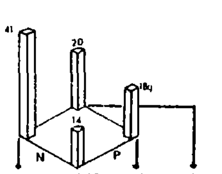


Figure 2. Interactions between any two elements.

Comparisons can only be made within one box using the least significant difference figure (5%); i.e. differences are only significant if greater than the LSD figure.

G. rosmarinifolia in Figure 3 illustrates the significant interactions of N with P and N with K and to a lesser extent P with K where growth was depressed. The main response was to nitrogen while there was a very small response to P and K on their own.

Grevillea robusta Experiments. There were no visual ratings and in Figure 1 the results divide between those treatments where plants grew vigorously with nitrogen and those with small yields due to having only 45 g of N/m^3 supplied. Figure 3 shows that there was a N x K interaction but no N x P or P x K interactions. Plants responded strongly to the main effect of N.

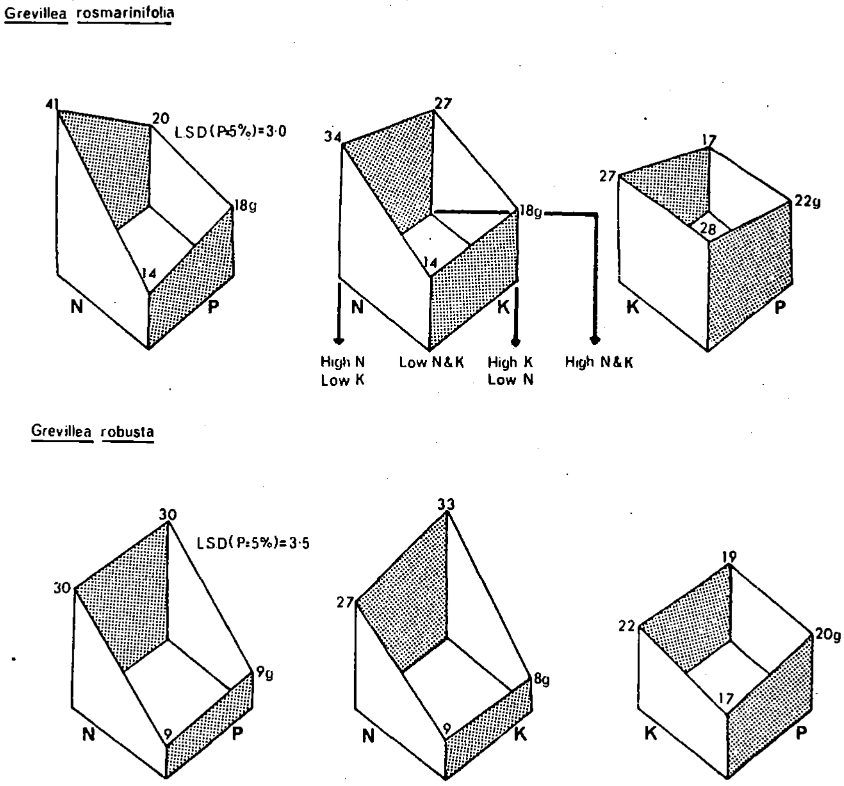


Figure 3. Three dimensional figures depicting the growth response (Dry wt. tops in g.) of container-grown shrubs to N.P.K. and the interactions involved.

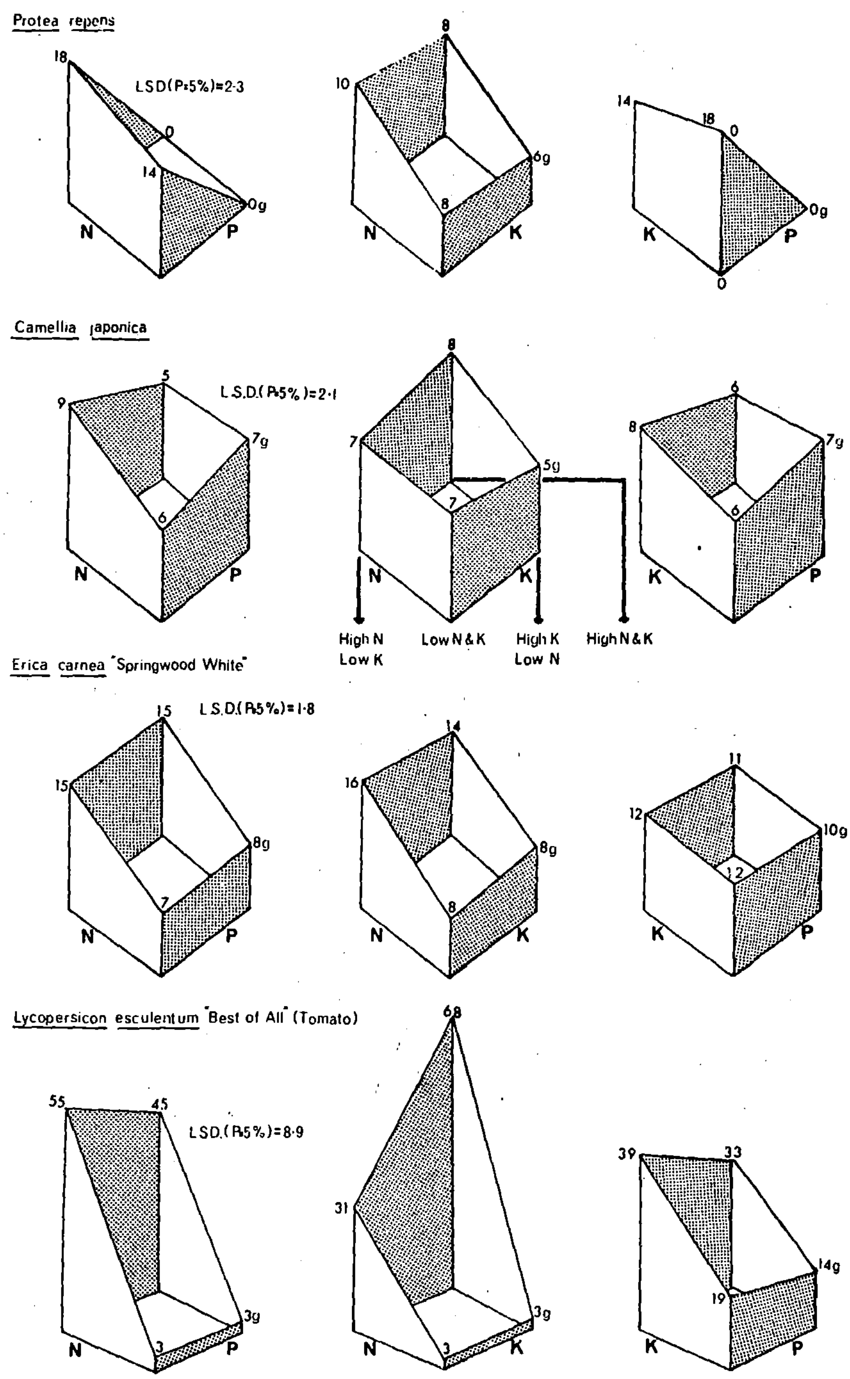


Figure 3 (cont.)

Protea repens Experiments. Visual ratings indicated a steady decline in those plants with 300g P/m^3 and there was a significant N x P interaction. The highest dry weight (Figure 1) was found in those plants supplied with 450:30:25 g/m^3 of N:P:K. respectively while the N.K. (6) and the low NPK (1) treatments were next highest.

Toxic effects of medium and high phosphate show clearly in Figure 3. Growth was mildly depressed by the N x K interaction. There was a mild response to nitrogen and a small depression of growth with high K levels. Plants were observed to show light to strong N toxicity symptoms (treatments 5 and 6) in the early stages of the experiment.

Camellia japonica Experiment. Plants with medium N (5), medium NK (6) and medium P (3) were significantly larger than those with other treatments (Figure 1). The next highest treatments were those with NP (7), NPK (8), PK (4) and K (2).

The interaction of N x P involved a slight depression in growth and the only other significant effect illustrated in Figure 3 was a fairly strong N response (left-hand diagram).

Erica carnea 'Springwood White' *Experiment.* There was a strong and significant response to nitrogen shown by treatments of 6 to 9. The latter was at a high rate of N plus medium P and K (900:300:250 g of NPK per m^3). The dominant main effect of nitrogen was shown in Figure 3 while there were no significant interactions or response to P or K.

Lycoperscion esculentum 'Best of All' (tomato) *Experiment.* All treatments with 450 and 900 g N/m^3 were significantly above all others (Figure 1). Treatment 11 and 10 with NPK in g/m^3 of 450/300/500 and 450/600/250 were the largest plants while treatment 6 with 450/30/250 were not significantly different from the latter.

The extremely strong N x K interaction is clearly shown in figure 3 where relative plant response at medium N and low K is doubled by having medium levels of N and K together. There was a slight depression with the N x P interaction and a strong response to the main effect of N and K.

DISCUSSION

The response to nitrogen was a common and major factor in the growth of all six groups of plants tested and, in all but tomatoes, treatment 5 with a N:P:K of 450:30:25 grew plants which were the largest in the trials (or not significantly different from the largest). It is indeed surprising that medium to high levels of N and other nutrients plus only very small levels of P and K grew good quality ericas, camellias and proteaceous shrubs.

Figure 4. The comparative growth response of the test species with three different treatments, giving some indication of the N.P., N.K., and P.K. interactions.

Left to right		High N & P	High N & K	High P & K
g/m³ of	N	450	450	45
potting	P	300	30	300
mix	K	25	250	250

High phosphate levels have been observed to cause severe losses with commercially grown nursery plants in the Proteaceae. In this work *Protea repens* did not survive in mixes with 300 g P/m^3 (approx. 3 kg/m^3 or 5 lb/yd^3 superphosphate) while growth of *Grevillea rosmarinifolia* was significantly reduced by similar P levels (Figure 4). The growth of the camellias and tomatoes was also significantly reduced as a result of an unfavourable N x P interaction. Therefore, with four species the response to nitrogen was depressed by the presence of medium levels of phosphate. In contrast, *Grevillea robusta* and the *Erica* 'Springwood White' grew well in mixes with NPK's of 450:300:25 g/m^3. *G. robusta* is native to the moist forested areas of Queensland while *G. rosmarinifolia* comes from the low fertility soils of the heathlands of Australia. The difference in habctat and soils probably accounts for the differing response of these two species and the fact that phosphate toxicity occurred with *G. rosmarinifolia* but not *G. robusta*. Other proteaceous plants may also tolerate medium phosphate levels; for example, macadamia is reported to respond to phosphate side dressings (12).

The difference in nutritional requirements between the two grevilleas is also shown by the fact that there was an unfavourable N x K interaction for *G. rosmarinifolia* while *G. robusta* responded where N and K were high together. The N x K interaction was a dominant feature in the nutritional response of tomatoes and the largest plants were those in treatment 12 with an N.P.K. of 900:600:500 g/m^3.

The proteas and, to a lesser extent, camellias were those plants which grew reasonably well at low and nil rates of N.P.K., probably because of their relatively slow growth rates. Standard fertiliser rates for proteas, suggested by Watson and Parvin (40), would appear to be undesirable because phosphate levels should be low. Proteas may be a low fertility plant but the two grevilleas responded strongly to nitrogen and grew poorly with low levels of this element. Although the *G. rosmarinifolia* is distributed on low fertility soils in its native habitat it appeared to have an even greater requirement for nitrogen than camellia. This may be due to the high potential for rapid growth of *G. rosmarinifolia*.

The tomato trial was started in mid-winter but this plant grew extremely rapidly and responded to medium N coupled with high K and also high P (Figure 1). This is in contrast to the growth supression with high nutrient level reported from England by Woods, et al (42) and Bunt (10). Higher light levels in winter in New Zealand than England may accoknt for the difference in findings and point to the need for caution when considering Northern hemisphere research in New Zealand.

There appears to be quite widely differing nutritional requirements both within the Proteaceae and between other plants.

It can be concluded that nurserymen should maintain at least medium levels of nitrogen with these types of plants grown in soil-less media, while phosphate levels should be minimised for certain Proteaceae, particularly while plants are young (17). This work re-enforces Furuta's (15) comments concerning the importance of quantitative research on such aspects as potting media and the prime importance of interactions when examining the nutrition of container-grown nursery stock.

LITERATURE CITED

1. Alvey N.G. 1955. Adapting John Innes Composts to grow ericas. *J. Roy. Hort. Soc.* 80: 376-381.
2. Anon, 1971. Container grown shrubs. *Luddington Expt. Hort. St. Lft.* 3 p.
3. Bates P.M. 1971. Composts for camellias. *N.Z. Cam. Bull.* VII (1): 25-8
4. Baylis G.T.S. 1972. Fungi, phosphorus and the evolution of root systems. *Search* 3 (7): 257-9.
5. Beadle N.C.W. 1954. Soil phosphate and the delimitation of plant communities in Eastern Australia. I *Ecol.* 35: 370-375.
6. Beadle N.C.W. 1962. Soil phosphate and the delimitation of plant communities in Eastern Australia II. *Ecol.* 43: 281-288.
7. Beadle, N.C.W. 1968. Some aspects of the ecology and physiology of Australian exeromorphic plants. *Aust. J. Sci.* 30: 348-355.
8. Bonner J. & Honda S. 1950. Experiments on camellia nutrition. *Cam. Res.* (Soc. Calif. Cam. Soc.) 15-21.
9. Boodley J.W. & Sheldrake R. 1963. Artificial soils for commercial plant growing. *Cornell Ext. Bull.* 1104 llp.
10. Bunt A.C. 1969. Peat sand substrates for plants grown in containers. *Pl. & Soil* XXX (1): 97-110.
11. Carter A.R. 1972. The effect of nitrogen on container grown shrubs in peat based substrates. *Act. Hort.* (26): 113-8
12. Cooil B.J., et al, 1966. Relationships of phosphorus supply to growth, yield and leaf composition in *Macadamia. Hawaii Ag. Expt. St. Tech. Bull.* 66, 71 p.
13. Furuta T. 1954. Analysis and rates of fertilisers on the growth of camellia plants in two Alabama soils. *Am. Cam. Yearbook*: 136-137.
14. Furuta T. et al 1954. Influence of rate and analysis of fertiliser on the growth and survival of three camellia varieties. *Am. Cam. Yr. Bk.* 138-40.
15. Furuta T. 1969. Operations research and ornamental horticulture. *Acta Hort.* 15 : 47-51.
16. Gray H. 1971. Light weight media for container growing of ericaceous plants. Proc. Int. Pl. Prop. Soc. 21: 416-419.
17. Grundon N.J. 1972. Mineral nutrition of some Queensland heath plants. *J. Ecol.* 60: 171-181.
18. Hewett H.M. 1972. A discussion of plant collapse. *Aust. pl.* 6: 359-366
19. Higgs A.L. 1970. The effect of planting depth and fertilizer on survival and growth of *Grevillea* and *Leptospermum* rooted cuttings. *Aust. Pl.* 6: 23-25.
20. Hocking P. & Thomas M.B. 1974. Evolution of the *Proteaceae* with cultural implications. *RNZIH Ann. J.* 2: 18-25.
21. Hockings F.D. 1970. Culture of grevillea. *Aust. Pl.* 6 (Dec): 10-13.
22. Hodge M.W. 1970. Growing grevillea. *Aust. Pl.* 6 (Dec): 2, 27; 28, 43.
23. Jeffrey D.W. 1964. The formation of polyphosphate in *Banksia ornata*, an Australian heathplant. *Aust. J. Biol. Sci.* 17: 845-854.
24. Jeffrey D.W. 1967. Phosphate nutrition of Australian heath plants I. The importance of proteoid roots in *Banksia (Proteaceae)*. *Aust. J. Bot.* 15: 403-411.

25. Lamont B. 1972. The effect of soil nutrients on the production of proteoid roots by *Hakea* species. *Aust. J. Bot.* 20: 27-40.
26. Lamont B. 1972. The morphology and anatomy of proteoid roots in the genus *Hakea*. *Aust. J. Bot.* 20: 155-174.
27. Moore C.W.E. 1966. Nutrition of *Grevillea robusta*. *Aust. Pl.* 4: 39-47.
28. Moore C.W.E. & Keratis K. 1966. Nutrition of *Grevillea robusta* *Aust. J. Bot.* 14: 151-163.
29. North C.P. & Wallace 1966. Planting mixtures, fertilisers and camellia culture N.Z. *Cam. Bull.* IV 5: 20-31.
30. Nuffer D. 1963. Peat-perlite mixtures in container growing. *Proc. Int. Pl. Prop. Soc.* 13: 286-287.
31. Parvin P.E. et al 1973. Proteas: developmental research for a new cut flower crop. *Hort. Sci.* 8(4): 299-303
32. Purnell H.M. 1960. Studies in the family *Proteaceae* I. Anatomy and morphology of the roots of some Victorian species. *Aust. J. Bot.* 8: 38-50.
33. Rao C.V. 1971. Proteaceae Bot. Mono. (6) *Counc. Sci. Ind. Res.* New Delhi 208 p
34. Specht R.L. 1963. Dark Island heath (Ninety Mile Plain, South Australia) VII. The effect of fertilisers on composition and growth, 1950-60. *Aust. J. Bot.* 11: 67-94.
35. Specht R.L. & Groves R.H. 1966. A comparison of the phosphate nutrition of Australian heath plants and introduced economic plants. *Aust. J. Bot.* 14: 201-221.
36. Stevens W. R. 1965. Growing South African *Proteaceae* in New Zealand. *J. Soc. S. Bot. Afr.* 51: 19-21.
37. Stewart T.G.A. 1959. Some aspects of soil ecology p 303-314. In Biogeography and ecology in Australia. W. Junk, The Hague.
38. Van Staden J. 1967. Deficiences of major nutrient elements in *Protea cynaroides* Linn., grown in sand culture. I Foliar symptoms of deficiences. *J. S. Afr. Bot. Soc* 33: 59-64.
39. Vogts M.M. 1954. Growing Proteaceae in the summer-rainfall area. *J. Bot. Soc. S. Afr.* 40: 18-21.
40. Watson D.P. & Parvin P.E. 1970. Culture of ornamental proteas. *Hawaii Ag. Expt. St. Res. Bul.* 147 24p.
41. Wood J.C. 1959. The phytogeography of Australia (in relation to radiation of *Eucalyptus*, *Acacia* etc) p 291-302. *In* Biogeography and ecology in Australia. W. Junk, The Hague.
42. Woods M.J. et al 1969. The effect of potassium and phosphorus fertiliser on tomatoes propagated in peat. *Acta Hort.* 8: 13-22

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Nitrogen in Container Mixes and a Simplified Method for Comparative Analysis

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ABSTRACT

The attention of nurserymen is drawn to the importance of nitrogen for plants. Nitrogen release in overseas and N.Z. potting mixes, and from individual fertilisers is examined. Nitrogen release patterns are simplified to allow a working method for comparing nitrogen levels at given times in different potting mixes.

1. INTRODUCTION

Decision making and examination of chemical ingredients of potting mixes is often based on very little background information. This article attempts to provide some of the guidelines needed for planning new mixes or appraising mixes in use.

Furuta (1969) states that a study of potting mixes requires an evaluation of physical, biological and chemical characteristics plus the quality, stability and cost of the ingredients. He points out that it is possible to establish tentative and minimum specifications for certain parameters of soil mixtures. The minimum requirement for fertilisation is given as 'slow release nitrogen incorporation, constant fertilisation with nitrogen and potassium, and phosphorus incorporated as single superphosphate'. The application of nitrogen is of high importance. Optimum growth of nursery plants depends on supplying nitrogen at the right levels and most nurserymen will have observed how too little gives deficiency while excess quickly leads to toxicity.

The nutrient supply characteristics of various fertilisers has been examined by various workers. Cochrane and Matkin (1967) found that the rate of nitrogen released from osmocote (N.P.K. 18-3.9-10.8), hoof and horn, and bone meal was roughly double that of magamp (fine grade) over the 14 week experiment. Prasad and Galagher (1972) used the same length experiment and found that the cumulative release of nitrogen from IBDU was 69%, and 30% from ureaformaldehyde at 14 weeks. Bridger et al (1961) found that the total nitrogen converted to nitrate was 58% for ureaformaldehyde and 65% for fine grade magamp after 11 weeks while with coarse grade magamp it was 34%. Allison (1973) points out that 87% of the nitrogen in urea is converted to nitrate in 20 days while it takes a further 40 days for an additional 1 or 2% more. Other workers like Bunt (1968) have looked at nutrient release and although the precise figures don't always agree because of the many variables effecting release, a general comparative picture can be drawn up. Figure 1 attempts to give the actual nitrogen release patterns based on the findings of these workers and estimates of probable release based on plant response in various nutrition trials.

Levels of other elements are comparatively much less critical and are less subject to loss by leaching, etc. Furthermore it has been found from nursery container research (Hocking & Thomas, 1974; Thomas, 1974) that nitrogen is often the dominant element for the growth of many container grown shrubs and that other major elements like phosphorus and potassium need only be supplied at moderate levels. Scott (1972) for example, found fast growing shrubs were tolerant to and responded strongly to high levels of liquid fed nitrogen.

This article closely examines levels of fertilisers and nitrogen supply in research and commercial potting mixes and attempts to make recommendations accordingly.

2. FERTILISER RELEASE PATTERNS

The large number of fast and slow or controlled release fertilisers available in New Zealand has meant that nurserymen have a wide range of materials to choose from. Richards (1969) (a) described the various fertilisers available and pointed out the importance of a knowledge of release characteristics in the light of the growing importance of slow release fertilisers in container growing in New Zealand. Amos (1973) discussed the chemical ingredients of NZ mixes based on slow and fast release fertilisers with reference to soil tests. Unfortunately these soil tests do not include nitrogen.

Nutrient release curves vary greatly in shape and in most cases the final few grams of nutrient may be very slowly released and the top of the curve levels off onto a plateau. In order to simplify analysis of the chemical ingredients of mixes at different times nitrogen release curves have been replaced by straight lines as shown in Figure 2. Osmocote (N.P.K. 18-2.6-10) is referred to as a slow release fertiliser releasing nutrients for 8-9 months. The nitrogen release from this fertiliser is shown in Figure 2 as a straight line with 100% release at 8½ months. This straight line representation of release rates therefore gives a broad, simplified basis for analysis which should be suitable until more detailed research has been done on this aspect.

3. RESEARCH RESULTS

The results of a trial using medium and short term fertilisers in various soils and soilless mixes using tomatoes is shown in Figure 3. The release of nitrogen at given times is tabulated below Figure 3 using the linear release rates shown in Figure 2. Tomatoes are often referred to as a 'gross feeder' and have been shown to respond strongly to added nitrogen particularly when adequate potassium and phosphorus levels are supplied, Bunt (1969).

The tomato trial summarised in Figure 3 illustrates the value of slow release materials. Plants grown in the soil mixes with perlite (PPS) and vermiculite (VS) with total nutrients of NPK 225-150-125 g/m³ were of similar size irrespective of the fact that one was with fast and one with slow release fertilisers. But when plants were given 450-300-250g NPK / m³, supplied from fast release fertilisers, their growth was significantly smaller in both the vermiculite mixes (V&VS) and the perlite mix (PP), than the plants supplied with slow release fertiliser and the same total nutrients (PP & PPS). All plants given the highest rate of fast release fertilisers in the three mixes were very severely stunted and contrasted with the again significantly larger plants supplied with the two slow release materials.

These results serve as a guide for looking at suitable levels of nitrogen release for container grown plants, particularly rapid growing subjects. The figures giving release of nitrogen in grams per month under Figure 3 indicate why the fast release materials were comparatively unsatisfactory even for a short term crop like tomatoes. The release of nitrogen from the fast release fertilisers in the first two months was obviously too high, and toxic. These excessive nitrogen levels probably carried on well past the first month. The 450g N/m³ rate supplied from the slow release osmocote fertilisers was probably close to the point of maximum response with 121 gN/m³ being released per month for the first two months. The interesting aspect was that the tomatoes grown with the 900g N/m³ from slow release osmocote in peat:perlite:soil were not significantly larger than with 450g total N/m³, indicating that increasing the rate from 121 to 250g N/m³ per month proved of no value. These plants at the 900g N/m³ rate were therefore in the luxury range of nutrient response, furthermore, when grown in peat:perlite at this high rate, these levels proved slightly toxic and the plants were significantly smaller than the corresponding mix with ⅓ soil. Soil acted as a good buffer with the highest fertiliser rates with the perlite and vermiculite mixes and also the vermiculite mix at the 225N-150P-125K level. Soil in the mix with both fertiliser types improved the growth of plants where nutrient levels were low. Plant growth was significantly greater when soil was added to the vermiculite and perlite mixes at the lowest fertiliser rate and in the vermiculite mix at the 225g N/m³ rate as compared to the corresponding light weight mixes. Soil can act as a nutrient supply or 'mop-up' toxic levels of fertiliser, although it is noticeable that peat:perlite was one of the three mixes with the largest plants.

Three additional and separate trials show further aspects on fertiliser response and nitrogen requirements of plants. These were 2^3 factorial experiments with a total of 14 treatments in each. The five balanced or medium treatments for two woody species and tomatoes were taken out of these trials and are shown in Figure 4.

The nil and low rates of fertiliser were obviously inferior to the medium rates. The most important aspects of these results is that the medium nutrient rate supplied from the 8-9 month fertiliser was

Nitrogen in Container Mixes — Simplified Comparative Analysis

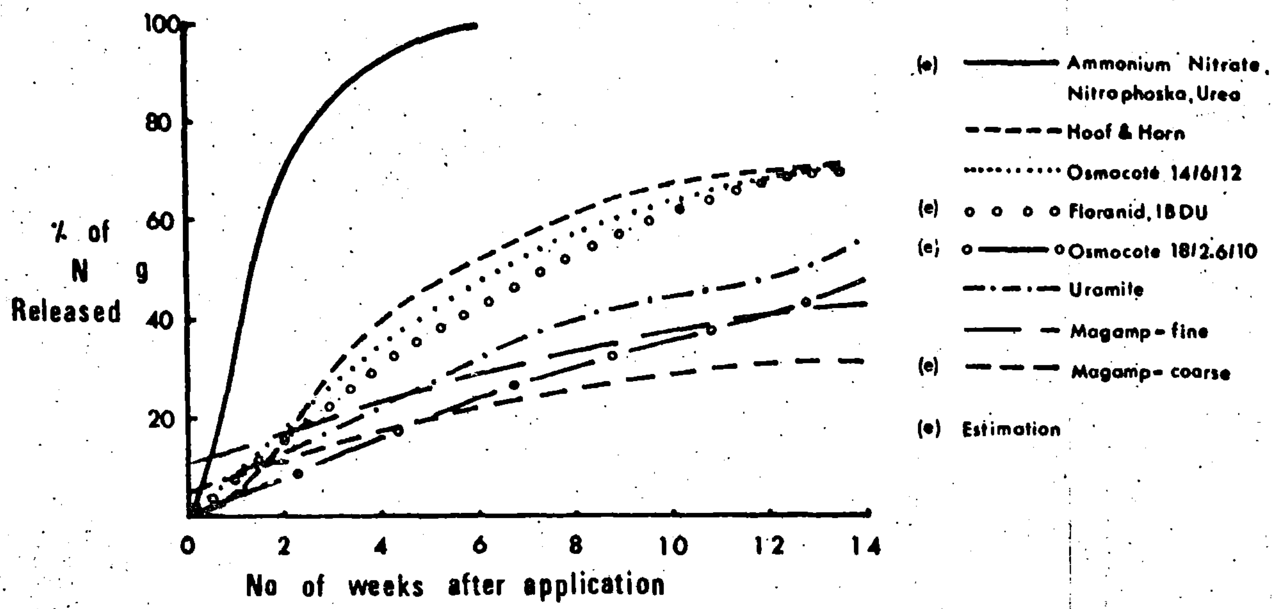


FIGURE 1: Diagram illustrating estimated and reported nitrogen release patterns from fertilisers.

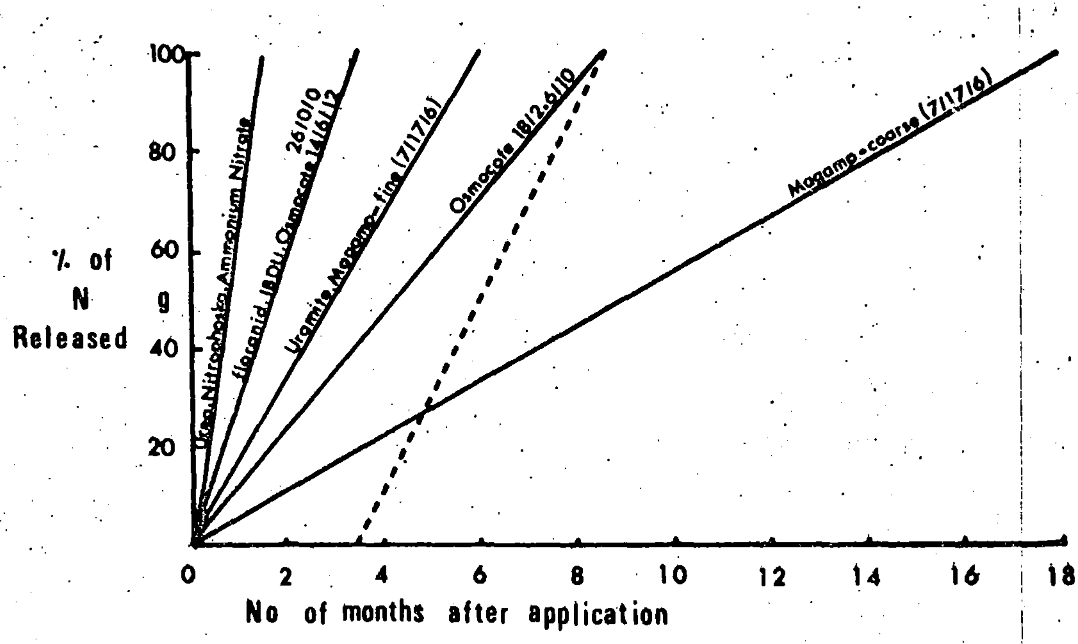
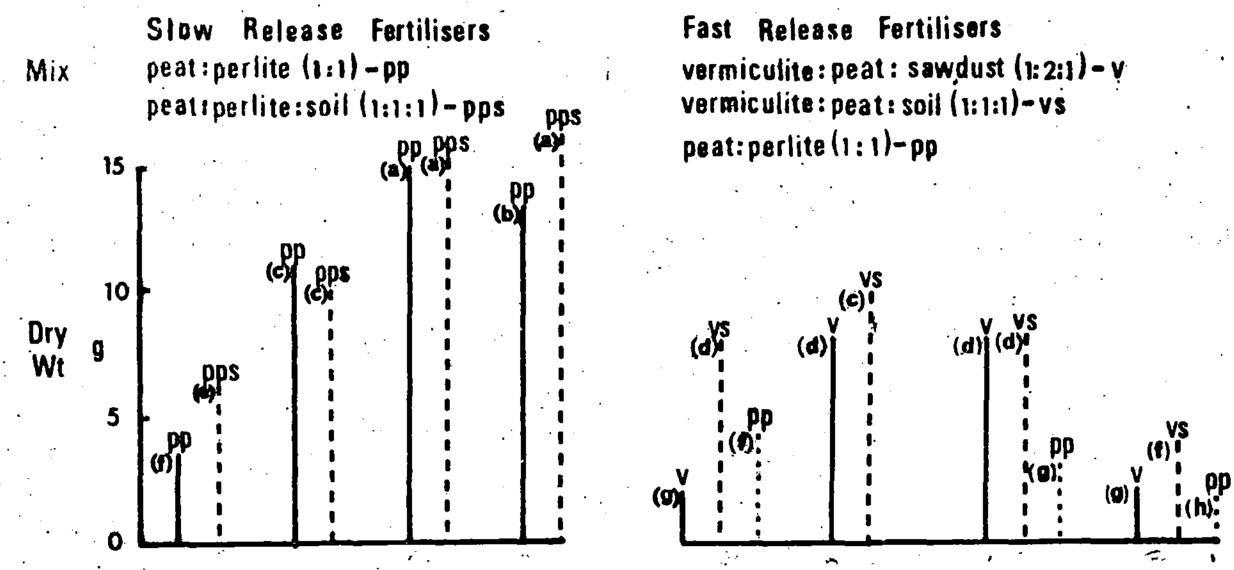


FIGURE 2: Diagram illustrating theoretical nitrogen release patterns from fertilizers assuming 100% efficiency.

FIGURE 3: A summary diagram depicting the growth response of tomatoes to fast and slow release fertilisers and in various media. (Levels of significance are shown by small letters in brackets above the columns – where small letters are common there is no significant difference at the 5% level using Duncan's test).



Nutrients g/m^3	N	45	225	450	900	45	225	450	900
	P	30	150	300	600	30	150	300	600
	K	25	125	250	500	25	125	250	500
g N/m^3 Av/mth	1st mth	5	57	121	250	18	138	288	587
	2nd mth	5	57	121	250	15	75	150	301
	3 & 4 mth	5	44	92	188	6	6	6	6

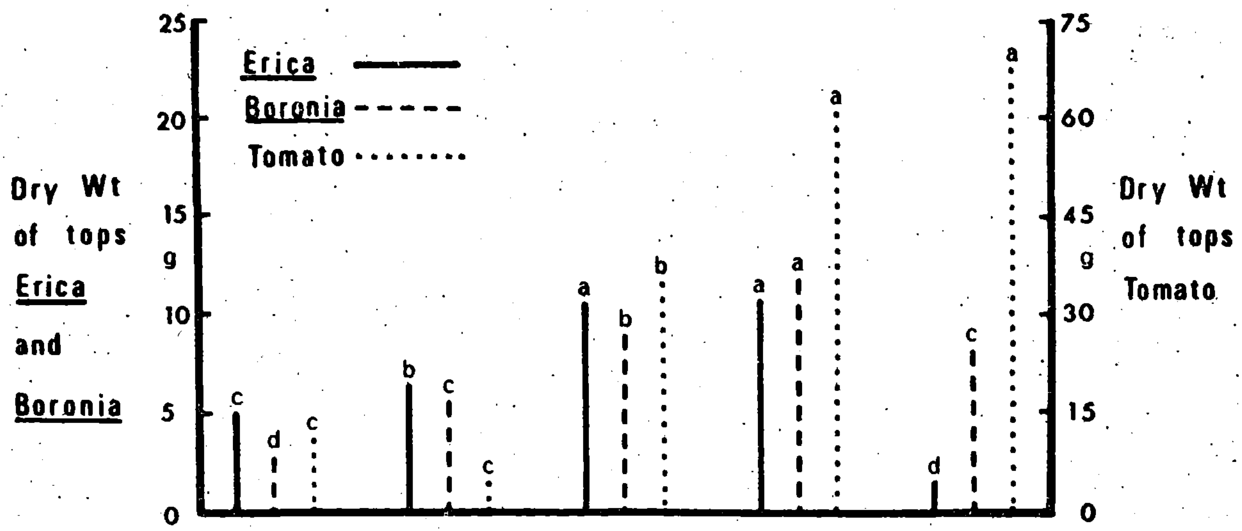
Fertilisers kg/m^3 (1 kg/m^3 = 1lb 11oz/cu. yd)

Osmocote 18-2.6-10	0.25	0.25	0.25	0.25	Floranid	0.12	0.12	0.12	0.12
					Nitrophoska Blue Sp.	0.12	0.12	0.12	0.12
Osmocote 26-0-0	–	0.69	1.56	3.29	Bone Flour	0.20	0.20	0.20	0.20
					Sulph. of Amm.	–	0.86	1.93	4.06
Superphosphate	0.26	1.60	3.26	6.60	Super	–	1.33	3.00	6.33
Sulph of Potash	–	0.26	0.58	1.22	Sulph. of Potash	–	0.26	0.58	1.22

All mixes received 6 kg/m^3 lime + trace elements.

Nitrogen in Container Mixes — Simplified Comparative Analysis

FIGURE 4: A summary diagram depicting the growth of *Erica carnea* 'Springwood White', *Boronia megastigma* and tomato at different fertilizer rates and from 3 separate factorial trials. (Levels of significance can only be compared within one species – with small letters in common shown in brackets above the columns, there is no significant difference at the 5% level using Duncan's test).



Main Fertilizer		Nil	8-9 month Osmocote Low	8-9 month Osmocote Medium	3-4 month Osmocote Medium	3-4 month Osmocote High
g per m^3	N	0	45	450	450	900
	P	0	30	300	300	600
	K	0	25	250	250	500
Average gN released per m^3 /month.	First 2 mths	0	5.3	53	121	250
	3 & 4 mths	0	5.3	53	.92	188
	5 & 6 mths	0	5.3	53	5.3	5.3
	7,8,9 mths	0	4.4	44	4.4	4.4
Fertilisers kg/m^3 (1 kg/m^3 = 1lb 11oz/ cu.yd)						
Osmocote 18 2.6 10		0	.25	2.50	.25	.25
Osmocote 26 0 0		0	0	0	1.56	3.29
Super		0	.26	2.60	3.26	6.59
Potash		0	0	0	.58	1.22

Mix: Peat:perlite (1:1) + fertilisers + 6 kg/m^3 lime + trace elements.

equal to the 3-4 month treatment with ericas. Growth was less for boronias and tomatoes than when supplied by the 3-4 month material. The differing growth from these treatments should be considered using the levels of nitrogen released on average per month and given in the table under Figure 4. It is reasonable to conclude that the 53 g N/month supplied from the 8-9 month osmocote (medium rate) is not adequate for optimum growth of shrubs. Probably 90-100g N/month from the slow release material would be a desirable level which is approximately the level of N supplied by the 3-4 month material for the first 4 months. The shrub crops were grown for 10-11 months and although nutrient release was relatively low in the first 4 months, with the 8-9 month fertiliser nutrient, release continued for most of the rest of the growing period. The short term materials would have ceased supply within 4-5 months. This was of course no problem for this second tomato trial which was grown for just under three months, although it was noticeable that the 900gN/m³ fertiliser rate was no significant advantage as was the case in the first trial (Figure 3). This high rate, released an average, 250gN/month over the first 2 months which caused severe toxicity for ericas and reduced growth in the boronias.

A rate of 90-100gN/m³ **per month** from slow release fertilisers would appear to be the requirement for tomatoes and shrubs from this data.

OTHER NUTRIENTS

Phosphorus supplied at 300gP/m³ using the fertiliser rates given under Figures 3 and 4 proved to be satisfactory in these and other shrub trials (except for proteaceae).

Potassium supplied at 250gK/m³ using the fertiliser rates given under Figures 3 and 4 proved to be satisfactory for shrubs. Tomatoes respond to higher rates.

Calcium is normally at adequate levels in potting mixes due to the standard use of lime. Magnesium is often supplied via dolomite or complete fertilisers. Trace elements especially iron, are often added especially to soilless mixes.

Research on nutrients for container mixes other than nitrogen will be published at a later date.

MANUFACTURERS' RECOMMENDATIONS FOR LONG TERM FERTILISERS

The rates with nutrient release and crops recommended for medium and long term slow release fertilisers are shown in Table 1 based on the simplified and theoretical release patterns in Figure 2.

The magamp recommendations for potted chrysanthemums and osmocote for shrubs, fall within the recommendations of approximately 100g N/m³ per month concluded at the end of the comments on research. The coarse magamp recommendation for shrubs appears too low and this rate should be supplemented with the fine grade material to give adequate monthly nitrogen release.

Floranid, osmocote (NPK 14-6-12) uramite and IBDU are shown at typical rates. Table 1 and also Figure 1 show that most of the nitrogen from these materials is released within **3-4 months** under warm (20°C) moist soil conditions.

In order to provide nitrogen over the same period as the 8-9 month osmocote a supplementary feeding will be necessary with medium term slow release fertilisers. For example, floranid used as part of the base fertiliser at 1.5 kg/m³ will need to be applied again at this rate 4-5 months after potting. The broken line labelled A in Figure 2 illustrates the theoretical use of a repeat application of medium term nitrogen.

A practical conversion chart (Table 1A) gives the approximate average nitrogen release per month from 1 kg/ m³ levels of various fertilisers. A nurseryman adding 1 kg of osmocote (NPK 14-6-12) plus 1 kg of floranid per cubic metre of mix can quickly see that this supplies 40 + 57 i.e. 97 g N/m³ each month for approximately 3½ months. This would be a good medium nitrogen supply for up to 4 months.

ANALYSIS OF COMMERCIAL MIXES

Birch (1970, a & b) reviewed and tabulated the ingredients and nutrient levels contained in the principal potting mixes used overseas. Some further analysis and conversion of these mixes to metric units is given in Table 2.

The basic mixes used overseas can be seen to be based on a relatively short term nitrogen supply. Birch (1970, b) pointed out the inherent danger of nitrogen starvation with U.C. mixes in Britain, and Richards (1969, a & b) points out some of the difficulties in trying to use U.C. mixes under New Zealand conditions. Naturally the John Innes mixes, which are based on soil, would not require feeding as early as the U.C. mixes. These mixes appear to have adequate nutrients for the first 4 months for most shrub crops, however supplementary feeding would

Nitrogen in Container Mixes — Simplified Comparative Analysis

TABLE 1

The monthly nitrogen release from certain commercial slow release fertilisers (using Figure 2) based on commercial or common application rates.

AVERAGE GRAMS OF N RELEASED PER M^3 /MONTH

Fertiliser	Rate of Application	First 2 months	3-4 months	5-6 months	7,8,9 months	10-18 months
Magamp (medium) – for potted chrysanthemums NPK (7-17.8-5)	10.38 kg/m^3 (17½ lbs/yd^3) (727gN/m^3)	121	121	121	–	–
Magamp (coarse) – for shrubs (7-17.8-5)	8.01 kg/m^3 (13½ lbs/yd^3) (561 gN/m^3)	31	31	31	31	31
Osmocote (18-2.6-10) low rate	2.37 kg/m^3 (4 lbs/yd^3) (427gN/m^3)	50	50	50	42	–
Osmocote (18-2.6-10) medium rate	4.15 kg/m^3 (7 lbs/yd^3) (747gN/m^3)	88	88	88	73	–
Osmocote (18-2.6-10) high rate	5.60 kg/m^3 (9½ lbs/yd^3) (1008gN/m^3)	119	119	119	98	–
Floranid (20-2-7)	1.5 kg/m^3 (2½ lbs/yd^3) (297gN/m^3)	86	64	–	–	–
Uramite (38-0-0)	0.89 kg/m^3 (1½ lbs/yd^3) (338gN/m^3)	56	56	56	–	–
IBDU (31-0-0)	1.04 kg/m^3 (1¾ lbs/yd^3) (322gN/m^3)	93	68	–	–	–

TABLE 1A

Basic Conversion chart for nurserymen showing approximate supply of nitrogen per month provided by 1 kg (1¾ lb) of specific fertilizers and release periods.

Fertiliser	gN released/ month	Approx. duration of supply (months)
Magamp (coarse)	4	18
Osmocote 18-2.6-10	21	8½
Magamp (fine)	12	6
Uramite	63	
Osmocote 14-6-12	40	3½
Osmocote 26-0-0	74	
Floranid	57	
IBDU	89	
Ammonium Nitrate	227	1½
Ammonium Sulphate	140	
Nitrophoska Blue Extra	80	
Urea	307	

TABLE 2

The monthly nitrogen release rate of various standard overseas potting mixes (based on Figure 2).

Mixes		Average N release/month (gN/m^3) First 2 months	3rd & 4th months	5th & 6th months	Total Nutrients (g/m^3) N	P	K
John Innes Potting Composts	JI1	40	30		141	94	237
	JI2	82	61		285	186	474
	JI3	122	91		426	280	711
University of California Composts (U.C. Composts)	1	17	–		33	117	142
	2	68	38		211	117	142
	3	119	76		389	117	142
Glasshouse Growers Research Institute (G.C.R.I. Mixes)	seed	28	–		56	58	139
Potting on high N reserve	1	97	37	37	342	117	292
	2	116	56	56	456	117	292
	3	134	74	74	564	117	292
Pricking out low N reserve		91	–		182	117	292
Kinsealy Composts	Tomato	140	47	47	468	105	308
	General	185	–		371	53	308
Peat-lite Mixes	seed	102	–		204	93	–
	growing on	45	–		89	93	222
Valentines Composts	seed	45	33		156	94	237
	potting	94	49		286	139	492

be necessary at approximately 6 months, depending on the season. It is noticeable that for the first 2 months the second level for most mixes, such as John Innes Potting No. 2, approximate to the guideline of 100g N/month recommended in this article. However the GCRI and Kinsealy mixes with 150-190g N/ m³ per month for the first 2 months show that 100g N/ month is a safe level.

The nutrient release from potting mixes used by a selection of nurseries in New Zealand are listed in Table 3. The principal fertilisers and type of production are also given. One of these mixes (G) is first looked at in more detail by examining the total amounts of nutrients released from this soil based mix and the average monthly nitrogen levels.

Mix G is a soil mix used for pot plants. It contains the following:

	N (g/m^3)	P	K
.24 kg/m^3 (.4 lb/yd) Uramite	90.2		
.48 kg/m^3 (.8 lb/yd) Serp. Superphosphate		33.2	
.24 kg/m^3 (.4 lb/yd) Sulphate of Potash			92.5
1.48 kg/m^3 (2½ lb) Osmocote 14-6-12	207.6	90.5	172.0
1.48 kg/m^3 (2½ lb) Osmocote 18-2.6-10	267.0	38.6	148.3
(Plus lime) Total	564.8	162.3	412.8

Examining the nitrogen part of the mix by looking at the average monthly N release rate gives:

Average release of N/month g/m^3	First 2 months	3rd & 4th months	5th & 6th months	7th — 9th month
Uramite	15.0	15.0	15.0	–
Osmocote 14-6-12	59.4	44.5	–	–
Osmocote 18-2.6-10	31.5	31.5	31.5	26.0
Total (as per table 3)	105.9	91.0	46.5	26.0
			Total N g/m^3	564.8

Mixes D and H will require side dressing after 6-7 months of warm conditions although feeding of mix H need only be in small increments since it is a soil based mix and nitrogen will be gradually released from magamp (coarse) for approximately 18 months. Mixes G and E would last an additional 1-2 months before available nitrogen becomes lacking. Nitrogen levels in mix E are higher than other mixes and are best suited to maintaining the growth of large shrubs and pot plants and could be toxic to small or fertiliser sensitive plants.

Some general observations can be made about the mixes listed in Table 3. Mixes I, C, and F appear to have an adequate supply of nitrogen for each of the first 4 months. Side dressing with equivalent N levels

TABLE 3

The monthly nitrogen release rate of various N.Z. commercial mixes (using Figure 2) grouped under the crops grown.

Average release of N month in g m³

Mix	First 2 months	3rd & 4th months	5th & 6th months	7th – 9th month	10th-18th month	Total g/m³ N	P	K	
Trees and Shrubs									
A	63	63	63	52	–	534	211	297	Mainly long term osmocote with superphosphate.
B	126	126	126	73	–	975	108	415	Long term osmocote with some uramite.
C	135	102	–	–	–	474	131	421	Mainly floranid with some serp. super and sulphate of potash.
Trees, Shrubs and Pot Plants									
D	75	75	75	–	–	450	107	463	Equal amounts of uramite, superphosphate and sulphate of potash.
E	150	150	150	–	–	900	427	925	Based on large applications of uramite, superphosphate and sulphate of potash.
F	131	98	–	–	–	458	224	334	Mainly based on short term osmocote.
Pot Plants									
G	106	91	47	26	–	565	162	413	Based mainly on short & long term osmocote.
H	78	73	56	5	5	474	498	234	Mainly based on long and shorter term magamp.
I	156	80	–	–	–	472	147	245	Based on floranid, nitrophoska blue extra, bone dust and superphosphate.
Bedding Plants									
J	118	42	–	–	–	320	83	231	Based on nitrolime, IBDU, serp. super & sulphate of potash.
K	43	9	–	–	–	104	148	231	Based on superphosphate, sulphate of potash nitrolime & blood and bone.
L	38	38	38	–	–	228	107	231	Based on uramite, superphosphate & sulphate of potash.

as in the base dressing will be required at 5 or 6 months or as the growing season dictates (broken line Figure 3). For example pot plants grown in heated glasshouses may have an extended growing season.

Mix A is a relatively low nutrition mix which could be used for initial potting into small containers. Mix B will last an equal period (10 months) without sidedressing being required. In this latter mix nutrient levels are more than adequate and in fact care would be needed with small plants of difficult subjects like waratahs or proteas. Mixes J, K and L are used for bedding plants. Mix J is probably closest to the optimum nitrogen content while rapidly growing plants in mixes K and L will need sidedressing for optimum growth. Recent work indicates that bedding plants are much more responsive to balanced NPK levels than are shrubs. For example recent research with marigolds indicated that they grew best with 120 gN m³ per month from slow release fertiliser plus a base dressing of 300 gP/m³ and 250 gK m³. The phosphate levels in Mix E and H appear to be excessive while the amount of potassium in mixes C, E and D is unnecessarily high and could potentially initiate nutritional problems since the potash fertilisers are relatively short term. Potassium levels in mixes J, K and L appear to be at a good level for bedding plants and in fact the amount of P & K does not appear to be too low in any of the N.Z. commercial mixes listed in Table 3.

ECONOMIC ASPECTS

Minard (1968) and Harre (1973) reviewed general plant nutrition and the types of fertilisers used in horticulture, including prices and unit costs of nutrients supplied. Van den Broek (1972) looked at the costing of container production based on a total of 100,000 units and including all aspects from capital, labour and materials to sales expenses. He found that the compost was one of the largest cost items apart from raising the plants ready for potting. The initial phase of a study into the economic aspects of container mixes with cost benefit analysis

TABLE 4

The cost of materials to make up two soilless potting mixes each with the same physical ingredients.

Physical Components of both mixes

1 pt peat at $15/m³

1 pt sand at $6/m³ ∴total cost per m³ = $10.50

Osmocote Mix (8 - 9 month release)

A. Fertilizers	Rate	Cost	Actual Cost	g nutrient/m³ N	P	K
Osmocote 18-2.6-10	4.15 kg/m³	$19.75/22.7 kg	$3.61	747	108	415
Superphosphate	2 kg/m³	$2.15/50 kg	.09		180	
Lime	6 kg/m³	$0.50/50 kg	.06			
		Total	$3.76	747	288	415

(average release of N/m³ per month = 83g)

∴ total cost of mix $/m³ = $14.26

Assuming 1 m³ fills 352 PB5's (2.85 litre bag) ∴ cost per plant:

Fertilizers	1.07 cents
Physical compon.	2.98
Total	4.05 cents/plant

Floranid Mix (3 - 4 month release)

B. Fertilizers	Rate	Cost	Actual Cost	g nutrient/m³ N	P	K
Floranid	1.54 kg/m³	$12.87/25 kg	$0.79	308	31	123
Superphosphate	2.86 kg/m³	$2.15/50 kg	0.12		257	
Lime	6 kg/m³	$0.50/50 kg	0.06			
		Total	$0.97	308	288	123
	+ Floranid sidedressing		$0.79 (average release of N/m³ per month = 77 g)			

= $1.76 ∴ total cost = $12.26

Assuming 1 m³ fills 352 PB5's (2.85 litre bag)

∴ Cost per plant:

Base fertilisers	.28 cents
Floranid sidedressing	.22
Physical component	2.98
Total	3.48 cents/plant

on the chemical and physical aspects has been completed at Lincoln College (Stevens 1973). Stevens (1974) reports that subsequent studies on 25 representative container mixes have shown that fertiliser costs comprise between 0.8 and 35% of all costs (including materials, labour, machinery depreciation etc)., of preparing a commercial potting mix. However, it should not be inferred that higher fertiliser costs automatically mean greater benefits in plant growth.

The cost of materials (only) to make up a soilless mix based on 8-9 month osmocote and one for floranid are shown in Table 4. In the osmocote mix the cost of materials in the mix is close to 4 cents per plant in a PB5 (2.85 l) bag. With the floranid one side dressing would need to be carried out to give a release of nitrogen equal to that of the osmocote at 88.3g N m³ per month (288 gP m³ is contained equally in each mix). Allowing for the base + sidedressing the material costs of the floranid mix comes to 3.48 cents per plant or .57 cents per plant less than the alternative mix. Therefore the nurserymen must consider whether the labour involved in sidedressing, the efficiency of sidedressing (possibility of poor fertiliser distribution) and other factors such as the availability of labour make one of these types of mixes more suitable to his operation than the other.

CONCLUSIONS

Nitrogen nutrition is of major importance in container culture. Given actual nutrient levels of 200-300g P/m³, 150-250g K/m³ plus a base dressing of 3-6 kg lime/m³, magnesium and a supply of trace elements the nitrogen release should be approximately **100 gN/m³ per month.** For small sensitive or slow growing plants this level could be reduced to 60-70g N/m³ while large fast growing plants being potted prior to a growth period could be supplied with approximately 120 g N/m³ per month. Sidedressings of nitrogen may be required supplement base dressings of short term slow release fertilisers.

ACKNOWLEDGEMENT

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REFERENCES

ALLISON, F. E. 1973: Soil organic matter and its role in crop production. Elsevier. London. 637 p.
AMOS, J. 1973: What to put in the mix — chemical ingredients. Container Mixes Semin., Auckland: 17-23.
BIRCH, P. D. W. 1970(a): Loamless composts 5. A comparison of the available mixes. Comm. Grow. (Jan) (365): 121-124, 134.
BIRCH, P. D. W. 1970(a): Loamless composts 6. Further comparison of available mixes. Comm. Grow. (Feb) (3866): 163, 164.
BRIDGER, G. L. et al. 1961; Metal ammonium phosphates as fertilizers. 140th Mtg. Am. Chem. Soc. 25 p.
BUNT, A. C. 1968: Slow-release fertilisers in peat-sand composts. Acta Hort. 8: 55-61.
BUNT, A. C. 1969: Peat and sand substrates for plants grown in containers. Pl. & Soil XXXI (1): 97-110.
COCHRANE, R. D. & MATKIN, O. A. 1967: Nutrient supply characteristics of slow release fertilizers. Pl. Propag. 12(4): 2-10.
FURUTA, T. 1969: Operations research and ornamental horticulture. Acta Hort. 15: 47-56.
HARRE, A. J. 1973: The formulation, properties and evaluation of fertilizers in general use. Proc. Flow. Grow. Course (June): 32-40.
HOCKING, P. J. & THOMAS, M. B. 1974: Evolution of the Proteaceae with cultural implications. Ann. J. R. N.Z. I. H. 2: 18-25. (Republished 1974 Comm. Hort. 6(2): 16A-18).
MINARD, H. R. G. 1968: Fertilizer problems in horticultural. Proc. Short Crse Nurs. & Pl. Dist. (ChCh): 41-48.
PRASAD, M. & GALLAGHER, P. A. 1972: Sulphur coated urea, casein and other slow release nitrogen fertilizers for tomato production. Acta Hort. 26: 165-74.
RICHARDS, M. 1969a: Fertilizers and container production Comm. Hort. (April), 1(1): 4, 6-7.
RICHARDS, M. 1969(b): Composts for containers. Comm. Hort (Sept), 1(1): 14-17.
SCOTT, M. 1972: Fast growing container shrubs respond quickly to nitrogen feeds. Grow. (March), 77: 730-731.
STEVENS, R. B. 1973: The effect of cost and output of soil mixes — a study of innovation in horticulture. B. Hort. Sc. (Hons) Dissert. (Unpublished) 54 p.
STEVENS, R. B. 1974: pers. comm.
THOMAS, M. B. 1974: Research on the nutrition of container grown Proteaceae and other nursery stock. *In Press.*
VAN DE BROEK, C. J. 1972: The costing of container production. Gdns Chron. 171(1): 11.

Reprinted from Comm. Hort. 1975. 7 (5): 5, 7, 9, 10-13, 17

NITROGEN LEVELS IN CONTAINER MIXES

ABSTRACT
The attention of nurserymen is drawn to the importance of nitrogen for plants. Nitrogen release in overseas and N.Z. potting mixes, and from individual fertilisers is examined. Nitrogen release patterns are simplified to allow a working method for comparing nitrogen levels at given times in different potting mixes.

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Decision making and examination of chemical ingredients of potting mixes is often based on very little background information. This article attempts to provide some of the guidelines needed for planning new mixes or appraising mixes in use.

The application of nitrogen is of high importance. Optimum growth of nursery plants depends on supplying nitrogen at the right levels and most nurserymen will have observed how too little gives deficiency while excess quickly leads to toxicity.

Levels of other elements are comparatively much less critical and are less subject to loss by leaching etc. Furthermore, it has been found from nursery container research (Hocking & Thomas 1974; Thomas 1974) that nitrogen is often the dominant element for the growth of many container grown shrubs and that other major elements like phosphorus and potassium need only be supplied at moderate levels. Scott (1972) for example, found fast growing shrubs were tolerant to and responded strongly to high levels of liquid-fed nitrogen.

This article closely examines levels of fertilisers and nitrogen supply in research and commercial potting mixes and attemps to make recommendations accordingly.

Fertiliser Release Pattern

The large number of fast and slow or controlled release fertilisers available in New Zealand has meant that nurserymen have a wide range of materials to choose from.

Figure 1 attempts to give the actual nitrogen release patterns of a number of the more important nitrogenous fertilisers based on the findings of various workers and estimates of probable release based on plant response in various nutrition trials. Nutrient release curves vary greatly in shape and in most cases the final few grams of nutrient may be very slowly released and the top of the curve levels off onto a plateau.

In order to simplify analysis of the chemical ingredients of mixes at different times, nitrogen release curves have been replaced by straight lines as shown in Figure 2. Osmocote (N.P.K. 18-2.6-10) is referred to as a slow release fertiliser releasing nutrients for 8-9 months. The nitrogen release from this fertiliser is shown in Figure 2 as a straight line with 100% release at 8½ months. This straight line representation of release rates therefore gives a **broad, simplified** basis for analysis which should be suitable until more detailed research has been done on this aspect.

Research Results

The results of trials on five different plant species, some of which were described by Thomas and Spurway (1975) have been summarised in the form of nitrogen response curves, as shown in Figure 3. The different rates of fertiliser applied are analysed for nitrogen content, which are then converted in terms of **grams of nitrogen released per m^3 per month**, using Figure 2.

e.g. 5 kg/m^3 of Osmocote 18/2.6/10 contains 18% N

$$\text{wt. of N. in 5 kg} = 5000 \times \frac{18}{100} = 900\text{ g N.}$$

From Figure 2 – there is a theoretical 100% nitrogen release from Osmocote 18-2.6-10 after 8½ months.

$$\text{wt of N. released per month/m}^3 = \frac{900}{8.5} = 106\text{ g N.}$$

All species show a response to added nitrogen up to a level of approximately 106g N/m^3 per month. For four of the species increasing to a higher rate than 106g N/m^3 per month had the effect of reducing growth, the degree of toxicity varying with each species. Tomatoes are often referred to as a "gross feeder" and show a strong response to added nitrogen, particularly when adequate potassium and phosphorus levels were supplied, even up to a level of 220g N/m^3 per month.

A rate of 90-100 gN/m^3 **per month** from fertilisers in a potting mix would appear to be the requirement for most shrubs.

Other Nutrients

Phosophorus supplied at 200g P/m^3 proved to be satisfactory in these and other shrub trials (except for Proteaceal.)

Potassium supplied at 250g K/m^3 proved to be satisfactory for shrubs. Tomatoes respond to higher rates.

Calcium is normally at adequate levels in potting mixes due to the standard use of lime. Magnesium is often supplied via dolomite or complete fertilisers. Trace elements especially iron, are often added especially to soilless mixes.

Manufacturers' Recommendations for long term fertilisers

The rates, with nutrient release, recommended for medium and long term slow release fertilisers are shown in Table 1 based on the simplified and theoretical release patterns in Figure 2.

The Magamp recommendations for potted chrysanthemums and Osmocote for shrubs fall within the recommendations of approximately 100g N/m3 per month concluded at the end of the comments on research. The coarse Magamp recommendation for shrubs appears too low and this rate should be supplemented with the fine grade material to give adequate monthly nitrogen release.

Floranid, Osmocote (NPK 14-6-12), Uramite and IBDU are shown at typical rates. Table 1 and also Figure 1 show that most of the nitrogen under these materials is released within 3-4 months under warm (20°C) moist soil conditions.

In order to provide nitrogen over the same period as the 8-9 month Osmocote, a supplementary feeding will be necessary with medium term slow release fertilisers. For example, Floranid used as part of the base fertiliser at 1.5 kg/m^3 will need to be applied again at this rate 4-5 months after potting. The broken line labelled A in Figure 2 illustrates the theoretical use of a repeat application of medium term nitrogen.

A practical conversion chart (Table 1A) gives the approximate average nitrogen release per month from 1 kg/m^3 levels of various fertilisers. A nurseryman adding 1 kg of Osmocote (NPK 14-6-12) plus 1 kg of Floranid per cubic metre of mix can quickly see that this supplies 40 + 57 i.e. 97 g N/m^3 each month for approximately 3½ months. This would be a good medium nitrogen supply for up to 4 months.

Analysis of Commercial Mixes

Birch (1970, a & b) reviewed and tabulated the ingredients and nutrient levels contained in the principal potting mixes used overseas. Some further analysis and conversion of these mixes to metric units is given in Table 2.

The basic mixes used overseas can be seen to be based on a relatively short term nitrogen supply. Birch (1970, b) pointed out the inherent danger of nitrogen starvation with U.C. mixes in Britain, and Richards (1969, a & b) points out some of the difficulties in trying to use U.C. mixes under New Zealand conditions. Naturally the John Innes mixes, which are based on soil, would not require feeding as early as the U.C. mixes. These mixes appear to have adequate nutrients for the first 4 months for most shrub crops, however supplementary feeding would be necessary at approximately 6 months, depending on the season. It is noticeable that the John Innes No. 2. and the U.C. compost C No. 3 approximate to the guideline of 100g N/month recommended in this article. However, the Kinsealy mixes with 140 and 185g N/m^3 per month for the first 2 months show that 100g N/month is a safe level.

	Average release of N/month g/m^3			
	First 2 months	3rd & 4th months	5th & 6th months	7th - 9th months
Uramite	15.0	15.0	15.0	–
Osmocote 14-6-12	59.4	44.5	–	–
Osmocote 18-2.6-10	31.5	31.5	31.5	26.0
Total (as per table 3)	105.9	91.0	46.5	26.0
			Total N g/m^3	564.8

The nutrient release from potting mixes used by a selection of nurseries in New Zealand are listed in Table 3. The principal fertilisers and type of production are also given. One of these mixes (E) is first looked at in more detail by examining the total amounts of nutrients released from this soil based mix and the average monthly nitrogen levels.

Mixes C and F will require side dressing after 6-7 months of warm conditions although feeding of mix F need only be in small increments since it is a soil based mix and nitrogen will be gradually released from Magamp (coarse) for approximately 18 months. Mixes E & D would last slightly longer than C and F, before available nitrogen becomes lacking. Nitrogen levels in mix D are higher than

TABLE 1

The monthly nitrogen release from certain commercial slow release fertilisers (using Figure 2) based on commercial or common application rates.

Fertiliser	Rate of Application	Average g N released/m^3 month
Magamp (fine) for potted chrysanthemums NPK (7-17.8-5)	10.38 kg/m^3 (17½ lbs/yd^3)	121
Magamp (coarse) – for shrubs (7-17.8-5)	8.01 kg/m^3 (13½ lbs/yd^3)	31
Osmocote (18-2.6-10) low rate	2.37 kg/m^3 (4 lbs/yd^3)	50
Osmocote (18-2.6-10) medium rate	4.15 kg/m^3 (7lbs/yd^3)	88
Osmocote (18-2.6-10) high rate	5.60 kg/m^3 (9½ lbs/yd^3)	119
Floranid (20-2-7)	1.5 kg/m^3 (2½ lbs/yd^3)	86
Uramite (38-0-0)	0.89 kg/m^3 (1½ lbs/yd^3)	56
IBDU (31-0-0)	1.04 kg/m^3 (1¾ lbgs/yd^3)	93

TABLE 1A
Basic Conversion chart for nurserymen showing approximate supply of nitrogen per month provided by 1 kg (1¾lb) of specific fertilisers and release periods.

Fertiliser	gN released /month	Approx. duration of supply (months)
Magamp (coarse)	4	18
Osmocote 18-2.6-10	21	8½
Magamp (fine)	12	6
Uramite	63	
Osmocote 14-6-12	40	3½
Osmocote 26-0-0	74	
Floranid	57	
IBDU	89	
Ammonium Nitrate	227	1½
Ammonium Sulphate	140	
Nitrophoska Blue Extra	80	
Urea	307	

TABLE 2
The monthly nitrogen release rate of various standard overseas potting mixes (based on Figure 2)

Mixes		Average N release/month (gN/m^3) 1st & 2nd months	3rd & 4th months	5th & 6th months	Total Nutrients (g/m^3) N	P	K
John Innes Potting Composts	J11	40	30		141	94	237
	J12	82	61		285	186	474
	J13	122	91		426	280	711
University of California Composts (U.C. Composts) (C)	1	17	–		33	117	142
	2	68	38		211	117	142
	3	119	76		389	117	142
Kinsealy Composts	Tomato	140	47	47	468	105	308
	General	185			371	53	308

Mix E is a soil mix used for pot plants. It contains the following:

	N (g/m^3)	P	K
.24 kg/m^3 Uramite	90.2		
.48 kg/m^3 Serp.Superphosphate		33.2	
.24 kg/m^3 Sulphate of Potash			92.5
1.48 kg/m^3 Osmocote 14-6-12	207.6	90.5	172.0
1.48 kg/m^3 Osmocote 18-26-10	267.0	38.6	148.3
(Plus lime) Total	564.8	162.3	412.8

Examining the nitrogen part of the mix by looking at the average monthly N release rate gives:

other mixes and are best suited to maintaining the growth of large shrubs, and pot plants and could be toxic to small or fertiliser sensitive plants.

Some general observations can be made about the mixes listed in Table 3. Mix B appears to have an adequate supply of nitrogen for each of the first 4 months. Side dressing with equivalent N levels as in the base dressing will be required at 5 or 6 months or as the growing season dictates. For example, pot plants grown in heated glasshouses may have an extended growing season.

Mix A is a relatively low nutrition mix which could be used for initial potting into small containers. Mixes G and H are used for bedding plants. Mix G is probably closest to the optimum nitrogen content while rapidly growing plants in mix H will need sidedressing for optimum growth. Recent work indicates that bedding plants are much more responsive to balanced NPK levels than are shrubs. For example recent research with marigolds indicated that they grew best with 120g n/m^3 per month from slow release fertiliser plus a base dressing of 200g P/m^3 and 250 gK/m^3. The phosphate levels in mix D and F appear to be excessive while the amount of potassium in mixes B, D and C is unnecessarily high and could potentially initiate nutritional problems since the potash fertilisers are relatively short term. Potassium levels in mixes G and H appear to be at a good level for bedding plants and in fact the amount of P & K does not appear to be too low in any of the N.Z. commercial mixes listed in Table 3.

Economic Aspects

Van den Broek (1972) looked at the costing of container production based on a total of 100,000 units and including all aspects from capital, labour and materials to sales expenses. He found that the compost was one of the largest cost items apart from raising the plants ready for potting. The initial phase of a study into the economic aspects of container mixes with cost benefit analysis on the chemical and physical aspects has been completed at Lincoln College (Stevens 1973). Stevens (1974) reports that subsequent studies on 25 representative container mixes have shown that fertiliser costs comprise between 0.8 and 35% of all costs (including materials, labour, machinery depreciation etc) of preparing a commercial potting mix. However, it should not be inferred that higher fertiliser costs automatically mean greater benefits in plant growth.

The cost of materials (only) to make two soilless

TABLE 3
The monthly nitrogen release rate of various N.Z. commercial mixes (using Figure 2) grouped under the crops grown.

	Average release of N per month in g/m³					Total g/m³			
Mix	1st 2 months	3rd & 4th months	5th & 6th months	7th-9th months	10th-18th months	N	P	K	
Trees and Shrubs and Pot Plants									
A	63	63	63	52	–	534	211	297	Mainly long term osmocote with superphosphate.
B	135	102	–	–	–	474	131	421	Mainly floranid with some serp. super and sulphate of potash.
C	75	75	75	–	–	450	107	463	Equal amounts of uramite, superphosphate and sulphate of potash.
D	150	150	150	–	–	900	427	925	Based on large applications of uramite, superphosphate and sulphate of potash.
Pot Plants									
E	106	91	47	26	–	565	162	413	Based mainly on short & long term osmocote.
F	78	73	56	5	5	474	498	234	Mainly based on long and shorter term magamp.
Bedding Plants									
G	118	42	–	–	–	320	83	231	Based on nitrolime, IBDU serp. super & sulphate of potash.
H	43	9	–	–	–	104	148	231	Based on superphosphate, sulphate of potash nitrolime & blood and bone.

B. TABLE 4 **Release Period for Fertilizers**

Release* Period (Mnths)	**18**	**8½**	**6**	**3½**	**1½**
Examples:	Magamp (coarse)	Osmocote (18-2.6-10)	Uramite, Magamp (fine)	Floranid, Osmocote (14/6/12) IBDU	Urea, Nitrophoska, Ammonium nitrate.

*Tentative figures based on Figure 2

C. FORMULA FOR CALCULATING FERTILIZER QUANTITIES FOR A REQUIRED NITROGEN LEVEL

$$\text{grams Fertiliser(s) needed per m}^3 = \frac{\text{grams N/m}^3\text{ (req'd per month)} \times \text{release period (months)} \times 100}{\text{\%N in fertiliser}}$$

D. FORMULA FOR COMPARING N LEVELS BETWEEN DIFFERENT MIXES

$$\text{Total grams N/m}^3\text{ per month for mix} = \frac{\text{grams fertilizer/m}^3 \times \text{\%N in fertiliser}}{\text{release period (months)} \times 100}$$

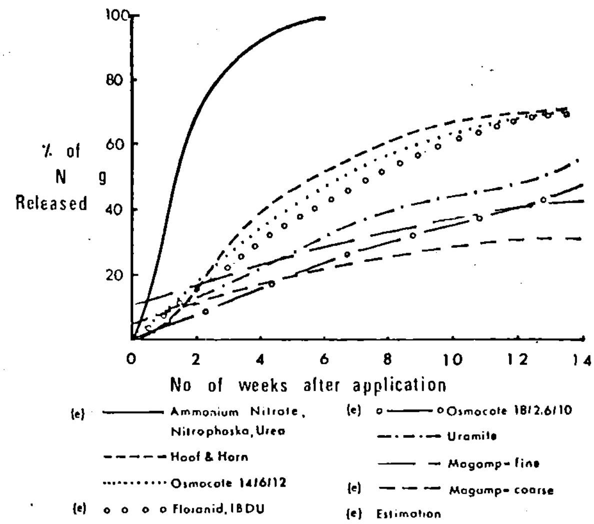

FIGURE 1: Diagram illustrating estimated and reported nitrogen release patterns from fertilisers.

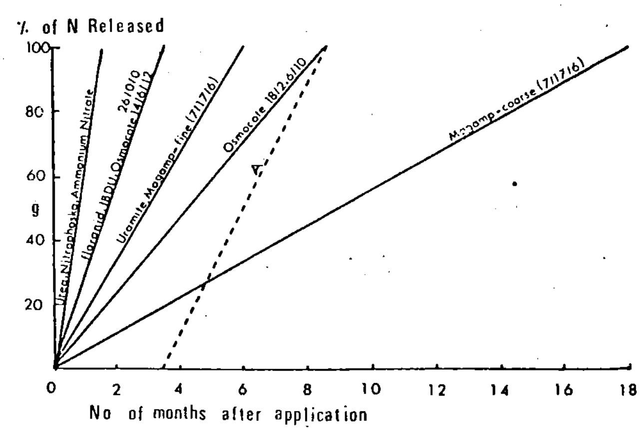

FIGURE 2: Diagram illustrating theoretical nitrogen release patterns from fertilizers assuming 100% efficiency.

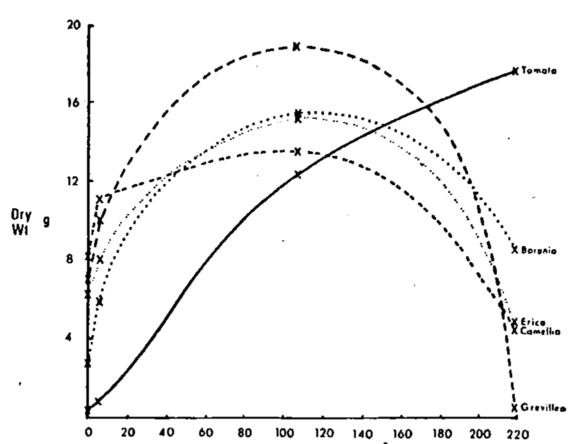

FIGURE 3: Nitrogen response curves; the growth of Lycopersicon esculentum (tomato), Boronia megastigma, Erica carnea 'Springwood White', Camellia japonica, and Grevillea rosmarinifolia in response to different nitrogen levels.

mixes was examined by Thomas and Spurway (1975). A mix based on the Osmocote 18-2.6-10 had a total cost of $14.26/m^3 for physical components and fertilisers while a similar mix based on Floranid costed out at $12.26/m^3. Using PB5 (2.8 l) planter bags the mix cost per potted plant would be 4.05 cents for the Osmocote and 3.48 cents/plant for the Floranid mix. The figures include an allowance for the cost of additional fertiliser to allow one sidedressing of Floranid. This is needed because nitrogen release in the Floranid mix would be exhausted approximately 3 months earlier than the Osmocote mix even though they were both containing sufficient to supply 80 g N/m^3 per month for the first 3-4 months.

The Floranid mix would be 0.57 cents cheaper per plant or $2 per 352 plants but has to still include the labour involved in sidedressing out of this amount. In addition other factors such as the efficiency of sidedressing (possibility of poor fertiliser distribution and uptake) and aspects like the availability of labour and the need to record which mixes need sidedressing all must be considered. It seems probable that the more expensive Osmocote mix is likely to be more convenient and efficient and possibly more profitable than using shorter term fertilisers with low initial costs.

Conclusions

Nitrogen is of major importance in container culture. Given actual nutrient levels of 200-300g P/m^3 , 150-250g K/m^3 plus a base dressing of 3-6 kg lime/m3, magnesium and a supply of trace elements the nitrogen release should be approximately 100g N/m^3 per month. For small sensitive or slow growing plants this level could be reduced to 60-70g N/m^3 while large fast growing plants being potted prior to a growth period could be supplied with approximately 120g N/m^3 per month. Sidedressings of nitrogen may be required to supplement base dressings of short term slow release fertilisers.

Acknowledgement

Thanks go to the New Zealand Nurserymen's Association members who provided details of their potting mixes for analysis. Thanks go to Rees Bros. Ltd for supplies of perlite and to Perlite Ltd for a grant which paid for labour to assist trail work.

References

BIRCH, P.D.W. 1970 (a) Loamless composts 5.A comparison of the available mixes. Comm. Grow. (Jan.) (365): 121-124, 134.

BIRCH, P.D.W. 1970 (b) Loamless composts 6. Further comparison of available mixes. Comm. Grow. (Feb.) (3866): 163, 164.

HOCKING, P.J. & THOMAS M.B. 1974: Evolution of the Proteaceae with cultural implications. Ann. J. R.N.Z.I.H. 2: 18-25 (Republished 1974 Comm. Hort. 6(2): 16A-18).

RICHARDS, M. 1969a. Fertilizers and container production Comm. Hort (April) 1(1): 4, 6, 7.

RICHARDS, M. 1969 Composts for containers. Comm. Hort (Sept), 1(1): 14-17.

SCOTT, M. 1972: Fast growing container shrubs respond quickly to nitrogen feeds. Grow. (March), 77:730-731.

STEVENS, R.B. 1973: The effect on cost and output of soil mixes — a study of innovation in horticulture. B. Hort. Sc. (Hons) Dissert. (Unpublished) 54p.

STEVENS, R.B. 1974 pers. comm.

THOMAS, M.B. 1974. Research on the nutrition of container grown Proteaceae and other nursery stock. Proc. Int.Pl. Propag. Soc. 24: (313-325)

THOMAS, M.B. & SPURWAY, M.I. 1975: Nitrogen in container mixes and a simplified method for comparative analysis. Roy. N.Z. Instit. Hort. Ann. J. 3:20-30.

VANDEBROEK, C.J. 1972: The costing of container production, Gdns Chron. 171 (1): 11.

ADDITIONAL FORMULAE, FACTS & FIGURES

A. CONVERSION FIGURES

1 oz fertilizer/1 cu. yd.	=	37.07 g/m^3
1 pound fertiliser/cu.yd.	=	593.24 g/m^3
1 kg./m^3	=	1.686lb/cu.yd. (approx 1 2/3 lb/cu.yd)
1 m^3	=	1,000 litres
∴1 kg/m^3	=	1 g./1

An ½ m^3 box has all its sides 79.37 cm long.

NUTRITION OF CONTAINER GROWN PLANTS WITH EMPHASIS ON THE PROTEACEAE

EXPERIMENTAL TABLES

NUTRITION OF CONTAINER GROWN PLANTS WITH EMPHASIS ON THE PROTEACEAE

EXPERIMENTAL TABLES

TABLE 1

Expt. A. Effects of N, P and K on the foliage growth (visual ratings and dry weights) of container grown *Grevillea rosmarinifolia*.

(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

Experiment A

	Nutrients (g/m^3)	Visual ratings 2 months	3 months	7 months	Dry Wt. (g/plt.)
N	45	4.03 ***	3.93 ***	2.50 ***	15.59 **
	450	3.33	3.40	3.34	32.41
P	30	4.05 ***	4.08 -	3.68 ***	29.33 ***
	300	3.31	3.24	2.17	18.67
K	25	3.67 -	3.88 ***	3.04 -	25.33 -
	250	3.70	3.45	2.81	22.67
LSD	(5%)	0.26	0.22	0.21	2.76

Significant Interactions

(P)	NP	-	***	***	***
	NK	-	***	**	**
	PK	***	***	**	***
	NPK	-	*	***	***
	CV (%)	25	21	26	41

Additional Treatments Experiment A.

Nutrients (g/m^3) N	P	K	Visual ratings 2 months	3 months	7 months	Dry Wt. (g/plt.)
900	300	250	1.42 CD d +	0.17 C c	0.08 C c	0.54 B d
450	600	250	2.00 BC bc	0.58 B b	0.54 BC bc	4.76 AB bc
450	300	500	2.71 B b	1.91 B b	0.79 B b	6.00 AB b
900	600	500	0.75 D d	0.25 C c	0.08 C c	1.60 B cd
0	0	0	4.54 A a	4.08 A a	2.08 A a	9.9 A a
CV (%)			50	58	64	151

(+ Duncan's letters given for means differing at the 1% (upper case) and 5% (lower case) levels of significance).

TABLE 1 contd.

Experiment B

	Nutrients (g/m^3)	Visual ratings 5 months	Dry Wt. (g/plt.)
N	45	1.85 *	8.02 ***
	450	2.23	18.60
P	30	2.71 ***	19.60 ***
	300	1.38	7.02
K	25	2.08 -	14.10 -
	250	2.00	12.52
LSD	(5%)	0.36	3.41

Significant Interactions

(P)	NP	***	**
	NK	-	-
	PK	-	-
	NPK	-	-
	CV (%)	43	63

TABLE 2

Interaction of N, P and K fertilisation on the foliage growth (visual ratings and dry weights) of *Grevillea rosmarinifolia.*

Experiment A

Fertilisation		Dry Wt. (g/plt.) K_0	K_1	Visual ratings 2 months	K_0	K_1	3 months		K_0	K_1
N_0	P_0	14.14	15.16	P_0	3.73	4.38	N_0	P_0	3.88	4.21
	P_1	15.15	17.89	P_1	3.60	3.02		P_1	3.88	3.75
N_1	P_0	42.39	45.64				N_1	P_0	4.21	4.04
	P_1	29.62	12.00					P_1	3.54	1.79
LSD (5%)		5.53			0.37				0.44	

7 months

		K_0	K_1
N_0	P_0	2.92	2.83
	P_1	2.00	2.25
N_1	P_0	4.36	4.59
	P_1	2.88	1.55
		0.42	

Experiment B

	Dry Wt. (g) P_0	P_1	Visual ratings 5 months	P_0	P_1
N_0	11.78	4.27	N_0	2.21	1.50
N_1	27.43	9.76	N_1	3.21	1.25
LSD (5%)	4.86			0.50	

TABLE 3

Effects of N, P and K on numbers of proteoid roots per container grown plant of *Grevillea rosmarinifolia.*

(Nutrients g/m^3)	Mean No. per plant	Significant Interactions
N 45	84.7 ***	(P)
450	24.1	
P 30	61.6 ***	
300	47.2	NP -
K 25	52.2 -	NK -
250	56.5	PK ***
		NPK *
LSD (5%)	8.2	CV% 53

TABLE 4

Interaction of N, P and K fertilisation on the numbers of proteoid roots per container grown plant of *Grevillea rosmarinifolia.*

		K_0	K_1
N_0	P_0	81.0	100.0
	P_1	78.5	79.3
N_1	P_0	18.9	46.4
	P_1	30.5	0.4
LSD (5%)		16	

TABLE 5

Effects of N, P and K fertilisation on the foliar levels of six nutrients in *Grevillea rosmarinifolia* (Experiment A).

Added Nutrients (g/m^3)		N	P	K	Mg	Ca	Na
		Foliar Analysis (g%)					
N	45	0.68 ***	0.41 ***	1.10 ***	0.28 *	0.71 ***	0.05 *
	450	1.29	0.24	0.63	0.25	0.55	0.06
P	30	0.93 *	0.22 ***	0.79 **	0.28 -	0.61 -	0.04 ***
	300	1.04	0.43	0.95	0.26	0.64	0.06
K	25	0.97 -	0.29 **	0.75 ***	0.28 -	0.62 -	0.05 -
	250	0.98	0.36	0.98	0.26	0.63	0.05
LSD (5%)		0.09	0.05	0.10	0.02	0.08	0.01
		Significant Interactions					
(P)	NP	-	-	-	***	-	*
	NK	-	-	-	-	-	-
	PK	***	-	-	*	#	-
	NPK	***	-	-	-	-	-
	CV%	15	23	17	14	20	32

TABLE 6

Interaction of N, P and K fertilisation on foliar nutrients in *Grevillea rosmarinifolia* (Experiment A).

Foliar Analysis (g%)

Fertilisation		Foliar N K_0	Foliar N K_1		Foliar Mg P_0	Foliar Mg P_1		Foliar Na P_0	Foliar Na P_1
N_0	P_0	0.66	0.66	N_0	0.31	0.25	N_0	0.04	0.04
	P_1	0.70	0.69	N_1	0.24	0.27	N_1	0.04	0.07
N_1	P_0	1.38	1.00	K_0	0.30	0.25			
	P_1	1.16	1.60	K_1	0.25	0.27			
LSD (5%)		0.19			0.03			0.02	

TABLE 7

Media N levels for *Grevillea rosmarinifolia* (Experiment A) sampled 2 months after potting.

Treatment Number	Total Fert. N g/m^3	ppm NH_4-N	ppm NO_3-N	ppm NH_4-N + NO_3-N
1	45	18.4	24.1	42.5
2	45	14.9	15.6	30.4
3	45	32.2	36.4	68.6
4	45	11.3	25.4	36.7
5	450	191.4	321.8	513.2
6	450	22.6	258.8	281.4
7	450	120.3	305.8	426.1
8	450	312.4	310.9	623.3
Additional Treatments				
1	900	479.6	249.0	728.6
2	450	183.2	315.2	498.2
3	450	242.1	301.0	543.1
4	900	699.3	299.3	998.6
5	0	7.1	9.9	17.0

Chapter two

TABLE 8

Soil nutrient levels, pH and soluble salts from Experiment A sampled 2 months after potting into peat:perlite (1:1, vv) mix.

Nutrients Added (g/m^3)	Nutrient Levels (ppm) P	K	Ca	Soluble Salts (%)	pH 2 months	7 months
45 N	-	-	4020	0.37	5.8	5.1
450 N	-	-	4830	0.46	5.4	5.1
900 N	-	-	6370	0.59	5.2	-
30 P	54	-	3435	0.38	5.8	5.3
300 P	177	-	4460	0.48	5.4	5.1
600 P	415	-	8650	0.52	5.2	-
25 K	-	54	4055	0.42	5.5	5.2
250 K	-	181	4547	0.51	5.5	5.2
500 K	-	260	7150	0.56	5.2	-
nil NPK	48	26	5600	0.30	6.1	5.3

Mean Mg levels (mean of all treatments) = 160.4 ppm

Chapter three

TABLE 1

Effects of N, P and K on the foliage growth (visual ratings and dry weights) of 4 container grown nursery plants.

(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

	Nutrients (g/m^3)	*Grevillea robusta* Dry Wt. (g)	*Protea repens* Visual ratings (weeks) 5	6	13	Dry Wt. (g/plt.)
N	45	8.77 ***	2.90 **	2.23 *	1.88 **	6.73 -
	450	30.03	2.35	1.90	1.45	8.12
P	30	19.35 -	3.95 ***	3.78 ***	3.33 ***	14.84 ***
	300	19.45	1.30	0.35	0	0
K	25	18.29 -	2.53 -	1.95 -	1.68 -	8.64 -
	250	20.50	2.72	2.18	1.65	6.21
	LSD (5%)	5.55	0.40	0.33	0.32	3.21
	Significant Interactions					
(P)	NP	-	*	#	**	-
	NK	-	#	-	-	-
	PK	-	-	-	-	-
	NPK	-	-	-	-	-
CV (%)		57	42	44	54	115

TABLE 1 contd.

Camellia japonica

	Nutrients (g/m^3)	Visual ratings (months) 2½	6½	9½	Dry Wt. (g/plt.)
N	45	3.87 ***	3.29 -	3.53 -	5.41 ***
	450	3.27	3.19	3.44	7.40
P	30	3.84 ***	3.34 -	3.71 **	6.55 -
	300	3.30	3.14	3.26	6.27
K	25	3.90 ***	3.40 #	3.59 -	6.70 -
	250	3.24	3.08	3.38	6.12
	LSD (5%)	0.28	0.32	0.32	1.15

Significant Interactions

(P)	NP	-	**	***	**
	NK	*	**	-	-
	PK	-	-	#	-
	NPK	-	-	-	-
CV (%)		28	36	24	63

TABLE 1 contd.

Lycopersicon esculentum
'Best of All' (tomato)

	Nutrients (g/m^3)	Visual ratings (months) 1	2	Dry Wt. (g/plt.)
N	45	1.55 ***	1.47 ***	0.29 ***
	450	4.08	4.07	4.96
P	30	2.78 -	2.80 -	2.88 *
	300	2.85	2.73	2.37
K	25	2.67 *	2.40 ***	1.68 ***
	250	2.97	3.13	3.57
	LSD (5%)	0.28	0.22	0.45

Significant Interactions

(P)	NP	*	***	*
	NK	-	***	***
	PK	-	-	-
	NPK	*	-	-
CV (%)		28	22	47

TABLE 2

Interaction of N, P and K fertilisation on the foliage growth (visual ratings and dry weights) of 3 plant species.

Protea repens

Visual ratings

	5 weeks		13 weeks	
	P_0	P_1	P_0	P_1
N_0	3.97	1.83	3.77	0
N_1	3.93	0.77	2.90	0
LSD (5%)	0.56		0.46	

Camellia japonica

	Dry Wt. (g/plt.)		Visual ratings. 2½ months		6½ months	
	P_0	P_1	K_0	K_1	P_0	P_1
N_0	4.66	6.17	4.34	3.40	3.14	3.44
N_1	8.43	6.37	3.46	3.08	3.54	2.84
					K_0	K_1
N_0					3.68	2.90
N_1					3.12	3.26
LSD (5%)	1.59		0.39		0.45	

9½ months

	P_0	P_1
N_0	3.36	3.70
N_1	4.06	2.82
LSD (5%)	0.46	

TABLE 2 contd.

Lycopersicon esculentum 'Best of All' (tomato)

Dry Wt. (g/plt.)

	P_0	P_1
N_0	0.29	0.29
N_1	5.47	4.45
	K_0	K_1
N_0	0.28	0.30
N_1	3.08	6.84
LSD (5%)	0.63	

Visual ratings. 1 month

		K_0	K_1
N_0	P_0	1.47	1.20
	P_1	1.47	2.07
N_1	P_0	3.93	4.53
	P_1	3.80	4.07
LSD (5%)		0.57	

2 months

	P_0	P_1
N_0	1.27	1.67
N_1	4.33	3.80
	K_0	K_1
N_0	1.33	1.60
N_1	3.47	4.67
LSD (5%)	0.31	

TABLE 3

Effects of additional fertiliser treatments on the foliage growth (visual ratings and dry weights) of 2 container grown plants.

Camellia japonica

Treatment Number	Nutrients (g/m^3)			Visual ratings (months)									Dry Wt. (g/plt.)		
	N	P	K	2½			6½			9½					
1	900	300	250	2.3	B	b	2.1	AB	b	1.6	B	b	6.5	A	a
2	450	600	250	2.2	B	b	1.7	B	b	1.4	BC	b	3.4	BC	b
3	450	300	500	2.4	B	b	2.4	AB	ab	2.1	AB	ab	4.3	AB	b
4	900	600	500	1.6	B	c	0.7	C	c	0.5	C	c	0.8	C	c
5	0	0	0	4.4	A	a	3.0	A	a	2.8	A	a	4.8	AB	ab
CV (%)				43			67			76			91		

Lycopersicon esculentum 'Best of All' (tomato)

Treatment Number	N	P	K		1 month			2 months			Dry Wt.		
1	900	300	250		4.3	AB	ab	4.5	A	a	7.2	A	b
2	450	600	250		4.3	AB	ab	4.8	A	a	8.6	A	ab
3	450	300	500		4.7	A	a	4.9	A	a	8.9	A	a
4	900	600	500		4.3	AB	ab	4.7	A	a	7.5	A	ab
5	0	0	0		1.6	C	c	1.6	C	c	0.3	C	d
6	450	300	250	SRO+	3.7	B	b	3.5	B	b	3.3	B	c
CV (%)					23			15			33		

+(SRO = slow release Osmocote 18/2.6/10 (8 - 9 month). All other additional treatments were based on Osmocote 26/0/0).

TABLE 4

Effects of N, P and K fertilisation on the foliar levels of 6 nutrients in 4 plant species.

Foliar Analysis (g%)

Grevillea robusta

Added Nutrients (g/m^3)		N	P	K	Mg	Ca
N	45	0.24 #	0.16 -	0.66 ***	0.16 #	0.76 ***
	450	0.29	0.16	0.42	0.15	0.60
P	30	0.23 *	0.12 ***	0.55 -	0.14 **	0.61 ***
	300	0.30	0.21	0.54	0.17	0.76
K	25	0.25 -	0.15 *	0.46 ***	0.16 -	0.67 -
	250	0.28	0.17	0.62	0.15	0.69
LSD (5%)		0.06	0.02	0.07	0.02	0.05

Significant Interactions

		N	P	K	Mg	Ca
(P)	NP	#	-	-	-	-
	NK	-	-	-	-	-
	PK	-	-	-	-	-
	NPK	-	-	-	#	#
	CV (%)	35	19	19	17	12

TABLE 4 contd.

Foliar Analysis (g%)

Camellia japonica

Added Nutrients (g/m^3)		N	P	K	Mg	Ca	Na
N	45	1.30 ***	0.19 -	1.35 **	0.44 **	1.43 ***	0.06 -
	450	2.02	0.18	1.02	0.53	1.77	0.08
P	30	1.58 -	0.14 ***	0.99 ***	0.51 -	1.43 ***	0.06 #
	300	1.74	0.23	1.38	0.46	1.78	0.08
K	25	1.62 -	0.18 -	1.04 **	0.52 *	1.60 -	0.06 -
	250	1.70	0.20	1.33	0.44	1.60	0.08
LSD (5%)		0.23	0.04	0.19	0.07	0.14	0.02

Significant Interactions

(P)		N	P	K	Mg	Ca	Na
	NP	-	**	-	-	-	-
	NK	-	-	-	-	-	-
	PK	-	-	-	-	*	-
	NPK	-	-	-	-	-	-
	CV (%)	21	35	25	21	14	37

TABLE 4 contd.

Foliar Analysis (g%)

Lycopersicon esculentum 'Best of All' (tomato)

Added Nutrients (g/m^3)		N	P	K	Mg	Ca	Na
N	45	2.97 ***	1.17 *	5.51 ***	0.95 ***	2.66 ***	0.22 ***
	450	5.16	0.97	3.54	1.25	1.94	0.31
P	30	3.68 ***	0.75 ***	4.62 -	1.24 ***	2.11 ***	0.26 -
	300	4.45	1.39	4.43	0.96	2.49	0.27
K	25	4.30 **	1.23 **	2.75 ***	1.22 ***	2.60 ***	0.34 ***
	250	3.83	0.91	6.30	0.98	2.00	0.19
LSD (5%)		0.32	0.18	0.64	0.12	0.20	0.04

Significant Interactions

(P)		N	P	K	Mg	Ca	Na
	NP	-	***	*	-	#	***
	NK	**	***	-	**	#	***
	PK	*	**	-	#	-	-
	NPK	*	-	-	-	-	-
	CV (%)	12	26	22	16	13	25

TABLE 4 contd.

Foliar Analysis (g%)

Protea repens

Added Nutrients (g/m^3)		N		P		K		Mg		Ca		Na	
N	45	1.17	***	0.71	-	1.28	**	0.29	***	0.59	***	0.34	**
	450	1.78		0.75		1.10		0.40		0.82		0.39	
P	30	0.88	***	0.15	***	0.82	***	0.21	***	0.48	***	0.28	***
	300	2.07		1.31		1.56		0.48		0.93		0.45	
K	25	1.52	-	0.68	*	0.86	***	0.34	-	0.71	-	0.35	-
	250	1.43		0.78		1.52		0.35		0.70		0.37	
LSD (5%)		0.10		0.10		0.12		0.04		0.08		0.04	

Significant Interactions

		N	P	K	Mg	Ca	Na
(P)	NP	-	-	-	-	***	*
	NK	-	-	-	-	-	-
	PK	-	*	***	-	-	*
	NPK	-	-	-	-	-	-
	CV (%)	16	30	23	27	25	24

TABLE 5

Interaction of N, P and K fertilisation on foliar nutrients in 4 plant species.

Foliar Analysis (g%)

Protea repens

Foliar P

	K_0	K_1
P_0	0.16	0.14
P_1	1.20	1.42
LSD (5%)	0.14	

Foliar K

	K_0	K_1
P_0	0.60	1.04
P_1	1.11	2.01
LSD (5%)	0.17	

Foliar Ca

	P_0	P_1
N_0	0.43	0.75
N_1	0.52	1.12
LSD (5%)	0.11	

Foliar Na

	P_0	P_1
N_0	0.23	0.44
N_1	0.33	0.46
	K_0	K_1
P_0	0.29	0.27
P_1	0.42	0.48
LSD (5%)	0.05	

Camellia japonica

Foliar P

	P_0	P_1
N_0	0.12	0.27
N_1	0.17	0.20
LSD (5%)	0.06	

Foliar Ca

	K_0	K_1
P_0	1.33	1.52
P_1	1.87	1.69
LSD (5%)	0.20	

TABLE 5 contd.

Foliar Analysis (g%)

Lycopersicon esculentum 'Best of All' (tomato)

Foliar N

		K_0	K_1
N_0	P_0	2.32	3.05
	P_1	3.56	2.94
N_1	P_0	5.18	4.17
	P_1	6.15	5.15
LSD (5%)		0.64	

Foliar P

	P_0	P_1
N_0	1.14	1.20
N_1	0.37	1.57

	K_0	K_1
P_0	0.75	0.76
P_1	1.70	1.07

	K_0	K_1
N_0	1.12	1.22
N_1	1.34	0.61

LSD (5%) 0.26

Foliar K

	P_0	P_1
N_0	5.98	5.03
N_1	3.25	3.83

LSD (5%) 0.90

Foliar Mg

	K_0	K_1
N_0	0.97	0.93
N_1	1.46	1.03

LSD (5%) 0.16

Foliar Na

	P_0	P_1
N_0	0.26	0.19
N_1	0.26	0.36

	K_0	K_1
N_0	0.24	0.21
N_1	0.44	0.18

LSD (5%) 0.06

TABLE 1

Details Of Individual Trials

Expt.	Plant Species	No. of treats.	Reps (plants per treat.)	Plants per pot	Method of Propagation	Date Bagged	Date Lifted
A	*Hakea laurina*	6	15	1	seed	30.8.72	2.5.73
B	*Lycopersicon esculentum* 'Best of All' (tomato)	6	20	5	seed	13.9.72	13.11.72
C	*Lycopersicon esculentum* 'Best of All' (tomato)	19	24	3	seed	16.10.72	22.11.72
D	*Grevillea rosmarinifolia*	30 + 6	10	1	cuttings	6.7.73	13.2.74
E	*Hakea laurina*	30 + 8	10	1	seed	29.8.73	16.5.74

TABLE 2

Effects of potting media and fertiliser levels on foliage dry weights of *Hakea laurina* (Experiment A) and *Lycopersicon esculentum* 'Best of All' (Experiment B) and root dry weight of the latter.

(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

		HAKEA	TOMATO	
		Mean dry wt. of foliage (g/plant)	Mean dry wt. of foliage (g/plant)	Mean dry wt. of roots (g/plant)
MEDIA				
	PP1 +	22.2 ***	3.6 *	1.2 ***
	S1PP1	33.9	4.7	2.0
	L.S.D. (5%)	3.5	1.0	0.4
NPK	(g nutrient/m^3)			
	0 :0 :0	29.7 ***	2.3 ***	1.3 ***
	45 :30 :25	35.9	3.1	0.9
	450:300:250	18.5	7.1	2.6
	L.S.D. (5%)	4.3	1.2	0.5

Significant Interactions

(P)				
	Media x NPK	***	**	-
	CV (%)	30	64	71

+PP1 = peat/perlite (1:1, vv), S1PP1 = soil:peat:perlite, (1:1:1, vv)

TABLE 3

The interaction of potting media and fertiliser levels on the foliage growth of *Hakea laurina* and *Lycopersicon esculentum* 'Best of All' (tomato).

Mean Dry Wt. Of Foliage (g/plant)

	HAKEA			TOMATO		
	N.P.K. (g nutrient/m^3)					
	0:0:0	45:30:25	450:300:250	0:0:0	45:30:25	450:300:250
MEDIA						
PP1	17.7	34.4	14.2	0.9	2.1	7.8
S1PP1	41.6	37.4	22.6	3.8	4.0	6.4
L.S.D. (5%)		6.1			1.7	

TABLE 4

Effects of nutrient levels, fertilisers and potting media on the foliage and root dry, weights of *Lycopersicon esculentum* 'Best of All' (tomato). (Experiment C). (3 plants per pot).

Treat No.	Nutrients g/m^3 N	P	K	Media and Fertilisers	Mean dry wt. (g/pot) TOPS Dry Wt.	Statistical rating		ROOTS Dry Wt.	Statistical rating	
1	45	30	25		4.0	G	f	6.7	BC	bcd
2	225	150	125	Peat:Perlite	11.6	C	c	10.5	A	a
3	450	300	250	(PPl) (1:1, vv)	15.4	A	a	10.9	A	a
4	900	600	500		13.8	B	b	4.3	DEF	fgh
5	45	30	25		7.2	E	e	4.6	DE	efg
6	225	150	125	Soil:Peat:Perlite	11.2	C	c	6.0	BCD	cd
7	450	300	250	(SlPPl) (1:1:1, vv)	15.5	A	a	3.2	EFG	hi
8	900	600	500	+ Osmocote	16.4	A	a	7.5	B	b
9	45	30	25		2.3	HI	g	1.8	GH	jk
10	225	150	125		9.0	D	d	7.1	BC	bc
11	450	300	250	Peat:Sawdust:Vermiculite	8.7	D	d	5.8	BCD	cde
12	900	600	500	(PSdV) (1:1:2, vv)	2.2	HI	g	2.2	GH	ijk
				+ Nitrophoska						
13	45	30	25		4.9	F	f	3.3	EFG	hi
14	450	300	250	Peat:Perlite	2.8	GH	g	3.6	EFG	ghi
15	900	600	500	(PPl) (1:1, vv)	0.9	I	h	1.0	H	k
				+ Nitrophoska						
16	45	30	25		8.8	D	d	5.4	CD	def
17	225	150	125	Soil:Peat:Vermiculite	11.4	C	c	6.9	BC	bc
18	450	300	250	(SlPV) (1:1:1, vv)	8.8	D	d	2.6	FGH	ij
19	900	600	500	+ Nitrophoska	4.1	FG	f	2.2	GH	ijk

TABLE 5

Soil nutrient levels, pH and soluble salts from container grown tomatoes (Experiment C) in various media and sampled 5 weeks after potting.

Treatment Number	Nutrients Added N	P	K	Media and Fertilisers		Nutrient Levels (ppm) P	K	Ca	Soluble Salts %	pH
1	45	30	25	P/Pl	Osm.	25	18	6400	0.28	6.5
2	225	150	125	P/Pl	Osm.	106	26	4800	0.51	6.0
3	450	300	250	P/Pl	Osm.	149	23	8200	0.40	6.0
4	900	600	500	P/Pl	Osm.	230	99	8800	0.53	5.5
5	45	30	25	Sl/P/Pl	Osm.	59	23	3040	0.25	6.5
9	45	30	25	P/Sd/V	Nitroph	30	82	3800	0.25	6.1
10	225	150	125	P/Sd/V	Nitroph	74	66	5200	0.36	5.8
11	450	300	250	P/Sd/V	Nitroph	184	30	5600	0.65	5.5
12	900	600	500	P/Sd/V	Nitroph	461	236	6400	0.52	5.4

Mean Mg levels for P/Pl treatments = 112 ppm

Mean Mg levels for P/Sd/V treatments = 147 ppm

TABLE 6

Effects of nutrient levels and soil added to peat:perlite on foliage dry weights of *Grevillea rosmarinifolia* and *Hakea laurina*.
(*** = P < 0.001; ** = P < 0.01; * = P < 0.05; # = P 0.05 - 0.10)

Mean Dry Wt. Of Foliage (g/plant)

	(g nutrient/m^3)	*Grevillea rosmarinifolia*	*Hakea laurina*
N	45	23.7 ***	18.0 ***
	450	29.2	22.0
P	30	27.2 *	29.1 ***
	300	25.7	10.9
K	25	24.2 ***	21.3 *
	250	28.7	18.8
LSD (5%)		1.5	2.1
Soil:Peat:Perlite (vv)			
	1:2:2	27.3 #	21.9 **
	1:1:1	26.8	20.4
	5:2.5:2.5	25.3	17.7
LSD (5%)		1.9	2.6

Significant Interactions

(P)			
	NP	***	*
	NK	-	**
	NS	***	***
	PK	***	***
	PS	*	#
	KS	***	-
	NPK	-	-
	NPS	*	-
	NKS	**	***
	PKS	**	-
	NPKS	#	*
	C.V. (%)	23	41

TABLE 7

Two Factor Interactions

The interaction of nutrient levels and soil added to peat:perlite on foliage dry weights of *Grevillea rosmarinifolia* and *Hakea laurina*.

Mean dry wt. of foliage (g/plant).

	(g nutrient/m^3)	*Grevillea rosmarinifolia*		*Hakea laurina*	
		P		P	
		30	300	30	300
N	45	22.5	24.8	25.9	10.1
	450	31.9	26.5	32.3	11.8
				K	
				25	250
N	45	-		17.7	18.4
	450			24.9	19.1
		K		K	
		25	250	25	250
P	30	26.6	27.9	32.7	25.5
	300	21.8	29.5	9.9	12.0
LSD (5%)		2.2		3.0	

		soil:peat:perlite (vv)			soil:peat:perlite (vv)		
		1:2:2	1:1:1	5:2.5:2.5	1:2:2	1:1:1	5:2.5:2.5
N	45	20.7	26.4	24.0	16.4	17.8	19.9
	450	34.0	27.1	26.5	27.5	23.0	15.6
P	30	27.9	26.5	27.4	32.5	29.5	25.3
	300	26.8	27.0	23.1	11.4	11.2	10.2
K	25	22.9	24.6	25.1			
	250	31.7	28.9	25.4		-	
LSD (5%)			2.6			3.6	

TABLE 8

Three Factor Interactions.

The interaction of nutrient levels and soil added to peat:perlite, on foliage dry weights of *Grevilla rosmarinifolia* and *Hakea laurina* (Experiments D and E).

Mean Dry Wt. Of Foliage (g/plant).

(g nutrient/m^3)		*Grevillea rosmarinifolia* soil:peat:perlite (vv) 1:2:2	1:1:1	5:2.5:2.5	*Hakea laurina* soil:peat:perlite (vv) 1:2:2	1:1:1	5:2.5:2.5
N_0	P_0	18.2	23.7	25.7			
	P_1	23.1	29.2	22.2			
N_1	P_0	37.6	29.3	29.0			
	P_1	30.4	24.9	24.1			
		1:2:2	**1:1:1**	**5:2.5:2.5**	**1:2:2**	**1:1:1**	**5:2.5:2.5**
N_C	K_0	17.7	23.4	21.7	12.2	18.3	22.5
	K_1	23.6	29.4	26.2	20.5	17.3	17.4
N_1	K_0	28.1	25.8	28.5	32.2	26.8	15.7
	K_1	39.9	28.4	24.6	22.8	19.1	15.4
		1:2:2	**1:1:1**	**5:2.5:2.5**			
P_0	K_0	26.2	26.7	26.8			
	K_1	29.6	26.2	27.9			
P_1	K_0	19.7	22.4	23.4			
	K_1	33.9	31.7	22.9			
LSD (5%)			3.7			5.2	

TABLE 9

Effects of N, P and K fertilisation on the foliar levels of six nutrients in *Grevillea rosmarinifolia* (Experiment D).

(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

Added Nutrients (g/m^3)		Foliar Analysis (g%) N	P	K	Mg	Ca	Na
N	45	0.51 ***	0.34 *	0.75 *	0.20 -	0.72 -	0.01 ***
	450	1.00	0.27	0.68	0.21	0.69	0.01
P	30	0.60 ***	0.17 ***	0.61 ***	0.18 **	0.59 **	0.01 #
	300	0.92	0.43	0.83	0.23	0.81	0.02
K	25	0.66 **	0.33 -	0.68 *	0.21 -	0.67 -	0.01 -
		0.86	0.28	0.76	0.20	0.73	0.01
LSD (5%)		0.14	0.07	0.06	0.03	0.17	0.01

(P)	Significant Interactions					
NP	-	*	-	-	-	-
NK	***	-	#	-	-	#
PK	#	-	**	*	-	-
NPK	*	-	**	-	-	-
CV (%)	28	39	13	22	37	127

TABLE 10

Interaction of N, P and K fertilisation on foliar nutrients in *Grevillea rosmarinifolia* (Experiment D).

Foliar Analysis (g%)

	Foliar N K_0	Foliar N K_1		Foliar P P_0	Foliar P P_1
N_0	0.28	0.75		0.17	0.52
N_1	1.03	0.98		0.18	0.35
LSD (5%)	0.19			0.11	

		Foliar K K_0	Foliar K K_1		Foliar Mg K_0	Foliar Mg K_1
N_0	P_0	0.60	0.73	P_0	0.20	0.16
	P_1	0.77	0.91	P_1	0.22	0.23
N_1	P_0	0.46	0.66			
	P_1	0.89	0.73			
LSD (5%)		0.27			0.04	

TABLE 11

The effects of additional fertiliser treatments on the foliage growth (visual ratings and dry weights) of two container grown plants (Experiment D and E).

Grevillea rosmarinifolia in soil/peat/sand

Treat. No.	Nutrients (g/m^3) N	P	K		Visual Ratings (months) 3			6½			Dry Wt. (g/plt.)		
1	900	300	250		2.5	BC	bc	3.0	BC	bc	22.8	C	bc
2	450	600	250		2.8	ABC	b	3.5	ABC	b	32.8	A	a
3	450	300	500		2.9	AB	ab	3.7	AB	b	31.1	AB	a
4	900	600	500		2.2	C	c	2.7	C	c	19.9	C	c
5	0	0	0		3.3	A	a	4.4	A	a	23.3	BC	bc
6	450	300	250	(SRO)+	2.9	AB	ab	3.5	ABC	b	28.0	ABC	ab
CV (%)					18			22			24		

Hakea laurina

	N	P	K		3½ months			Dry Wt. (g/plt.)		
1	900	300	250	SlPPl ++	1.1	C	c	2.1	C	d
2	450	600	250	SlPPl	1.5	C	c	1.6	C	d
3	450	300	500	SlPPl	1.5	C	c	3.2	C	cd
4	900	600	500	SlPPl	1.1	C	c	0	C	d
5	0	0	0	SlPPl	4.0	A	a	27.1	A	a
6	450	300	250	SlPPl (SRO)	2.8	B	b	8.0	C	c
7	45	30	25	PPl +++	3.2	AB	b	17.9	B	b
8	450	300	250	PPl	1.4	C	c	1.1	C	d
CV (%)					36			81		

\+ SRO = slow release Osmocote (18/2.6/10)

++ SlPPl = soil/peat/perlite (1:1:1, vv)

+++ PPl = peat/perlite (1:1, vv)

TABLE 1

Experiments	Plant Species	No. of Treatments	Reps. (plants/ treatment)	Date Bagged	Date Lifted
A	*Acacia verticillata* 'Rewa'	8 + 4	7	7.11.74	2.10.75
B	*Boronia megastigma*	8 + 6	25	2.1.73	3.12.73
C	*Choisya ternata*	8 + 2	9	5.2.74	28.4.75
D	*Eucalyptus notabilis*	8	8	2.5.74	16.9.74
	E. viminalis	8	8	2.5.74	16.9.74

TABLE 2

Effects of N, P and K on the foliage growth (visual ratings and dry weights) of 5 container grown plant species.
(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

	Nutrients (g/m^3)	*Acacia verticillata* 'Rewa' Visual rating 9 months	*Acacia verticillata* 'Rewa' Dry Wt. (g)	*Boronia megastigma* Visual rating 4 months	*Boronia megastigma* Dry Wt. (g)
N	45	2.94 ***	13.37 **	4.16 **	5.28 ***
	450	3.76	18.54	4.52	13.79
P	30	3.59 *	17.25 -	4.60 ***	11.03 ***
	300	3.10	14.55	4.07	8.05
K	25	3.34 -	14.78 -	4.31 -	9.80 -
	250	3.36	17.13	4.36	9.28
LSD (5%)		0.4	3.7	0.2	1.1
		Significant Interactions			
(P)	NP	-	-	-	***
	NK	-	-	#	-
	PK	-	-	-	-
	NPK	-	#	-	-
	CV (%)	23	43	18	43

	Nutrients (g/m^3)	*Choisya ternata* Visual rating 3½ months	*Choisya ternata* Dry Wt. (g)	*Eucalyptus notabilis* Visual rating 4 months	*Eucalyptus notabilis* Dry Wt. (g)
N	45	3.08 ***	3.59 ***	2.70 ***	4.11 ***
	450	3.64	8.34	4.22	25.66
P	30	3.42 -	6.01 -	3.47 -	14.66 -
	300	3.31	5.92	3.45	15.11
K	25	3.33 -	5.77 -	3.53 -	16.90 *
	250	3.39	6.16	3.39	12.87
LSD (5%)		0.4	1.6	0.4	3.1
		Significant Interactions			
(P)	NK	-	-	*	**
	CV (%)	23	57	21	42

TABLE 2 contd.

Eucalyptus viminalis

	Nutrients (g/m^3)	Visual rating 4 months	Dry Wt. (g)
N	45	3.19 ***	3.58 ***
	450	4.45	18.55
P	30	3.83 -	11.18 -
	300	3.80	10.95
K	25	3.87 -	11.16 -
	250	3.77	10.97
LSD (5%)		0.3	2.6

Significant Interactions

		none	none
(P)	CV (%)	17	47

TABLE 3

Effects of additional fertiliser treatments on the foliage growth of 3 container grown plant species.

Treatment Number	Nutrients (g/m^3)				Visual Rating		Dry Wt.		
	Acacia verticallata 'Rewa'								
					9 months		(g/plt.)		
1	900	300	250	(FRO)+	2.6	a	27.0	A	a
2	450	300	250	(SRO)	3.1	a	17.0	A	b
3	450	300	250	(F)	3.0	a	14.7	A	b
4	450	300	250	(U)	3.0	a	18.6	A	ab
CV (%)					69		43		
	Boronia megastigma								
					4 months		(g/plt.)		
1	900	300	250	(FRO)	3.8	AB abc	8.0	B	b
2	450	600	250	(FRO)	3.9	AB ab	9.4	AB	b
3	450	300	500	(FRO)	4.0	A a	12.0	A	a
4	900	600	500	(FRO)	3.4	AB bcd	7.7	B	b
5	0	0	0	(FRO)	3.2	B d	2.4	C	c
6	450	300	250	(SRO)	3.3	AB cd	8.8	B	b
CV (%)					28		50		
	Choisya ternata								
					3½ months		(g/plt.)		
1	900	300	250	(FRO)	3.8	a	12.2	a	
2	450	600	250	(FRO)	4.1	a	9.5	a	
CV (%)					30		42		

\+ FRO = fast release NPK from 3 - 4 month Osmocote (26/0/0)
SRO = slow release NPK from 8 - 9 month Osmocote (18/2.6/10)
F = Floranid Nitrophoska (20/2/7)
U = Uramite (38/0/0)

TABLE 4

The interaction of N, P and K on the foliage growth (visual ratings and dry weight) of 3 container grown plant species.

Acacia verticillata 'Rewa'

Dry Wt. (g/plt.)

N (g/m^3)	P	K (g/m^3) 25	250
45	30	13.8	16.6
	300	9.7	13.3
450	30	15.4	23.3
	300	20.2	15.4
LSD (5%)		5.2	

		Boronia megastigma Visual rating 4 months K (g/m^3)		*Boronia megastigma* Dry Wt. (g/plt.) P (g/m^3)		*Eucalyptus notabilis* Visual rating 4 months K (g/m^3)		*Eucalyptus notabilis* Dry Wt. (g/plt.) K (g/m^3)	
		25	250	30	300	25	250	25	250
N	45	4.0	4.3	5.6	4.9	2.6	2.8	4.0	4.2
(g/m^3)	450	4.6	4.4	16.4	11.2	4.5	3.9	29.8	21.5
LSD (5%)		0.3		1.6		0.5		3.7	

TABLE 5

Effect of N, P and K fertilisation on the foliar levels of 6 nutrients in 4 container grown plant species.

Foliar Analysis (g%)

Acacia verticillata 'Rewa'

	Added Nutrients (g/m^3)	N	P	K	Mg	Ca	Na
N	45	2.32 -	0.25 *	0.97 *	0.25 -	0.67 -	0.24 -
	450	2.23	0.17	0.81	0.27	0.63	0.25
P	30	2.23 -	0.12 ***	0.85 -	0.25 -	0.61 -	0.28 **
	300	2.32	0.30	0.93	0.27	0.69	0.21
K	25	2.18 -	0.24 -	0.78 **	0.26 -	0.66 -	0.28 **
	250	2.37	0.18	1.00	0.25	0.64	0.22
LSD (5%)		0.28	0.08	0.15	0.03	0.12	0.04

Significant Interactions

		N	P	K	Mg	Ca	Na
(P)	NP	-	-	-	-	-	-
	NK	-	-	-	-	-	*
	PK	-	-	-	-	-	-
	NPK	-	-	#	-	-	-
	CV(%)	19	56	26	18	30	25

Boronia megastigma

		N	P	K	Mg	Ca	Na
N	45	0.94 ***	0.20 ***	0.86 ***	0.27 *	0.75 -	0.26 -
	450	1.47	0.12	0.65	0.31	0.75	0.24
P	30	1.16 *	0.09 ***	0.72 -	0.29 -	0.69 **	0.26 -
	300	1.24	0.22	0.78	0.29	0.81	0.24
K	25	1.15 **	0.16 -	0.59 ***	0.31 *	0.79 *	0.26 -
	250	1.26	0.15	0.92	0.27	0.71	0.25
LSD (5%)		0.08	0.03	0.10	0.04	0.08	0.05

Significant Interactions

		N	P	K	Mg	Ca	Na
(P)	NP	-	***	*	*	-	-
	CV(%)	11	26	20	19	17	21

TABLE 5 contd.

Foliar Analysis (g%)

Choisya ternata

		N	P	K	Mg	Ca	Na
N	45	1.14 ***	0.27 **	1.65 ***	0.58 #	2.05 -	0.04 -
	450	1.44	0.24	0.98	0.63	2.17	0.04
P	30	1.29 -	0.23 ***	1.40 *	0.60 -	2.01 -	0.04 -
	300	1.29	0.28	1.23	0.62	2.22	0.04
K	25	1.31 -	0.26 -	1.20 **	0.61 -	2.07 -	0.04 -
	250	1.28	0.25	1.43	0.61	2.16	0.04
LSD (5%)		0.12	0.02	0.14	0.06	0.25	0.01

Significant Interactions

(P)	NP	***	*	-	-	-	-
	NK	-	-	-	*	-	-
	PK	-	-	-	-	-	-
	NPK	-	-	-	#	-	-
	CV(%)	14	10	17	14	19	23

TABLE 5 contd.

Foliar Analysis (g%)

Eucalyptus viminalis

		N	P	K	Mg	Ca	Na
N	45	1.10 **	0.69 ***	1.06 -	0.33 ***	1.51 ***	0.24 #
	450	1.50	0.35	0.99	0.25	0.99	0.28
P	30	1.31 -	0.33 ***	0.97 -	0.27 **	1.09 **	0.27 -
	300	1.30	0.71	1.08	0.31	1.41	0.24
K	25	1.27 -	0.58 *	0.87 ***	0.31 **	1.40 **	0.31 ***
	250	1.33	0.47	1.19	0.27	1.10	0.21
LSD (5%)		0.23	0.10	0.16	0.03	0.19	0.04

Significant Interactions

(P)	NP	-	***	-	***	**	-
	NK	**	*	**	-	-	#
	PK	#	-	-	-	-	-
	NPK	#	-	*	-	-	-
	CV(%)	27	30	25	16	24	24

TABLE 6

Interaction of N, P and K fertilisation on foliar nutrients in 4 container grown plant species.

Foliar Analysis (g%)

Acacia rewa

Foliar P	P_0	P_1
N_0	0.29	0.19
N_1	0.28	0.23
LSD (5%)	0.11	

Foliar Na	K_0	K_1
N_0	0.25	0.24
N_1	0.31	0.20
LSD (5%)	0.06	

Boronia megastigma

Foliar P	P_0	P_1
N_0	0.95	2.97
N_1	0.82	1.51
LSD (5%)	0.04	

Foliar K	P_0	P_1
N_0	0.88	0.84
N_1	0.58	0.73
LSD (5%)	0.14	

Foliar Mg	P_0	P_1
N_0	0.25	0.29
N_1	0.32	0.29
LSD (5%)	0.05	

Choisya ternata

Foliar N	P_0	P_1
N_0	1.04	1.24
N_1	1.54	1.34
LSD (5%)	0.17	

Foliar P	P_0	P_1
N_0	0.25	0.28
N_1	0.21	0.28
LSD (5%)	0.02	

Foliar Mg	K_0	K_1
N_0	0.61	0.55
N_1	0.60	0.67
LSD (5%)	0.08	

TABLE 6 contd.

Eucalyptus viminalis

Foliar N	K_0	K_1
N_0	1.22	0.99
N_1	1.31	1.69
LSD (5%)	0.33	

Foliar P	P_0	P_1
N_0	0.39	1.00
N_1	0.27	0.43

	K_0	K_1
N_0	0.80	0.59
N_1	0.35	0.34
LSD (5%)	0.14	

Foliar K		K_0	K_1
N_0	P_0	0.85	1.07
	P_1	1.24	1.09
N_1	P_0	0.80	1.16
	P_1	0.57	1.43
LSD (5%)		0.33	

Foliar Mg	P_0	P_1
N_0	0.27	0.38
N_1	0.26	0.25
LSD (5%)	0.04	

Foliar Ca	P_0	P_1
N_0	1.21	1.80
N_1	0.97	1.02
LSD (5%)	0.27	

TABLE 1

Details of Individual Trials.

Expt.	Plant Species	Number of Treatments	Reps. (Plants/ treatment)	Dates Bagged	Dates Side-Dressed	Dates Lifted
A	*Callistemon citrinus*	30	10	18.12.75	29.4.76	7.4.77
B	*Grevillea rosmarinifolia*	30	14	25. 2.73	20.9.73	20.2.74
C	*Hakea laurina*	30	9	2. 7.76	18.3.77	22.8.77

TABLE 2

Constants and coefficients of response surfaces for three container grown Australian shrubs:

X_1 = nitrogen; X_2 = phosphorus; X_3 = potassium; X_4 = lime.

(*** = P < 0.001; ** = P < 0.01; * = P < 0.05; # = P 0.05 - 0.10)

Callistemon citrinus

Term		Visual ratings 4½ months	Visual ratings 13 months	Dry Wt.
Constant		3.750	3.633	53.340
Linear	X_1	0.204 **	0.225 ***	11.345 ***
	X_2	0.004	0.000	- 0.260
	X_3	0.021	0.008	- 0.435
	X_4	0.004	0.008	- 1.083
Quadratic	X_1	-0.189 **	-0.188 **	- 3.717 **
	X_2	-0.051	-0.038	- 0.769
	X_3	-0.089	-0.075	- 0.127
	X_4	-0.001	0.050	0.872
Cross Product	$X_1 X_2$	-0.269 **	-0.138 #	- 3.160 *
	$X_1 X_3$	0.044	-0.038	0.165
	$X_1 X_4$	-0.069	-0.013	- 0.441
	$X_2 X_3$	-0.069	-0.100	- 2.568 #
	$X_2 X_4$	0.069	-0.025	2.299
	$X_3 X_4$	0.006	-0.025	0.484
SE: Linear terms		0.07	0.064	1.17
SE: Quadratic terms		0.07	0.059	1.10
SE: Interactive terms		0.09	0.078	1.44
C.V. (%)		33	29	36
R^2 (%)		16	17	44

TABLE 2 contd.

X_1 = nitrogen; X_2 = phosphorus; X_3 = potassium; X_4 = lime.

Grevillea rosmarinifolia

Term		Visual ratings (months) 2	3½	7	9½	Dry Wt.
Constant		2.310	2.548	4.202	3.821	29.240
Linear	X_1	-0.006	-0.068	0.407 ***	0.369 ***	9.996 ***
	X_2	-0.750 ***	-0.705 ***	-0.331 ***	-0.226 ***	-2.007 **
	X_3	0.048	0.015	0.143 **	0.077	0.805
	X_4	0.083	0.098 #	0.081	0.036	-1.047 #
Quadratic	X_1	0.095 #	0.057	-0.082 #	-0.089	-0.456
	X_2	0.247 ***	0.254 ***	0.052	0.009	-0.254
	X_3	0.006	-0.068	-0.109 *	-0.045	0.286
	X_4	0.060	0.013	-0.109 *	-0.098 #	-0.919
Cross Product	X_1 X_2	-0.188 *	-0.121 #	-0.048	-0.071	-1.600 *
	X_1 X_3	0.107	-0.004	-0.080	0.027	-0.731
	X_1 X_4	-0.000	-0.067	0.084	0.036	-0.534
	X_2 X_3	-0.107	0.022	-0.018	0.054	0.261
	X_2 X_4	-0.125 #	0.013	0.146 *	0.134 #	0.320
	X_3 X_4	0.027	0.058	0.107	0.089	0.922
SE: Linear terms		0.06	0.06	0.05	0.06	0.60
SE: Quadratic terms		0.06	0.06	0.05	0.06	0.56
SE: Interactive terms		0.07	0.07	0.07	0.08	0.73
C.V. (%)		42	39	24	32	39
R^2 (%)		55	52	44	27	65

TABLE 2 contd.

X_1 = nitrogen; X_2 = phosphorus; X_3 = potassium; X_4 = lime.

Hakea laurina

Term		Visual ratings (months) 5½	13½	Ht. (Months) 13½	Dry Wt.
Constant		3.278	3.463	9.770	36.617
Linear	X_1	0.278 ***	0.347 ***	0.711 ***	10.247 ***
	X_2	-0.509 ***	-0.403 ***	-0.503 ***	-7.002 ***
	X_3	0.102 #	0.069	0.150	0.894
	X_4	-0.019	0.005	0.147	-1.145
Quadratic	X_1	-0.157 **	-0.163 *	-0.638 **	-2.327 *
	X_2	-0.185 **	-0.233 ***	-0.605 **	-3.083 **
	X_3	0.065	0.059	0.363 #	1.839 #
	X_4	0.037	0.073	0.088	1.891 #
Cross Product	X_1 X_2	0.069	0.049	0.240	-1.214
	X_1 X_3	0.097	0.160 #	0.115	1.332
	X_1 X_4	-0.056	-0.007	0.260	-0.289
	X_2 X_3	0.056	0.049	0.013	0.861
	X_2 X_4	0.042	-0.035	-0.063	-1.615
	X_3 X_4	-0.042	0.049	0.131	0.408
SE: Linear terms		0.06	0.07	0.21	1.06
SE: Quadratic terms		0.06	0.06	0.19	0.90
SE: Interactive terms		0.07	0.08	0.25	1.29
C.V. (%)		29	30	33	44
R^2 (%)		45	39	40	53

TABLE 3

Effects of N, P, K and lime on the foliage growth (visual ratings and dry weights - predicted values) of 3 container grown shrubs.

Callistemon citrinus

Visual ratings

Level	4½ months N	P	K	Lime	13 months N	P	K	Lime
-2	2.6	3.5	3.4	3.7	2.4	3.5	3.3	3.8
-1	3.4	3.7	3.6	3.7	3.2	3.6	3.6	3.7
0	3.8	3.8	3.8	3.8	3.6	3.6	3.6	3.6
1	3.8	3.7	3.7	3.8	3.7	3.6	3.6	3.7
2	3.4	3.6	3.4	3.8	3.3	3.5	3.4	3.9

Mean Dry Wt. (g/plt.)

Level	N	P	K	Lime
-2	15.8	50.8	53.7	59.0
-1	38.3	52.8	53.6	55.3
0	53.3	53.3	53.3	53.3
1	61.0	52.3	52.8	53.1
2	61.2	49.7	52.0	54.7

TABLE 3 contd.

Grevillea rosmarinifolia

Visual ratings

Level	2 months N	P	K	Lime	3½ months N	P	K	Lime	7 months N	P	K	Lime
2	2.7	4.8	2.2	2.4	2.9	5.0	2.2	2.4	3.1	5.1	3.5	3.6
1	2.4	3.3	2.3	2.3	2.7	3.5	2.5	2.5	3.7	4.6	4.0	4.0
0	2.3	2.3	2.3	2.3	2.5	2.5	2.5	2.5	4.2	4.2	4.2	4.2
1	2.4	1.8	2.4	2.5	2.5	2.1	2.5	2.7	4.5	3.9	4.2	4.2
2	2.7	1.8	2.4	2.7	2.6	2.2	2.3	2.8	4.7	3.7	4.1	3.9

Level	9½ months N	P	K	Lime	Mean Dry Wt. (g/plt.) N	P	K	Lime
2	2.7	4.3	3.5	3.4	7.4	32.2	28.8	27.7
1	3.4	4.1	3.7	3.7	18.8	31.0	28.7	29.4
0	3.8	3.8	3.8	3.8	29.2	29.2	29.2	29.2
1	4.1	3.6	3.9	3.8	38.8	27.0	30.3	27.3
2	4.2	3.4	3.8	3.5	47.4	24.0	32.0	23.5

TABLE 3 contd.

Hakea laurina

Visual ratings

Level	5½ months N	5½ months P	5½ months K	5½ months Lime	13½ months N	13½ months P	13½ months K	13½ months Lime
-2	2.1	3.6	3.3	3.5	2.1	3.3	3.6	3.7
-1	2.8	3.6	3.2	3.3	3.0	3.6	3.5	3.5
0	3.3	3.3	3.3	3.3	3.5	3.5	3.5	3.5
1	3.4	2.6	3.4	3.3	3.6	2.8	3.6	3.5
2	3.2	1.5	3.7	3.4	3.5	1.7	3.8	3.8

13½ months

Level	Mean Foliage Ht. (cm/plt). N	P	K	Lime	Mean Dry Wt. (g/plt.) N	P	K	Lime
-2	5.8	10.4	10.9	9.8	6.8	38.3	42.2	46.5
-1	8.4	10.7	10.0	9.7	24.0	40.5	37.6	39.7
0	9.8	9.8	9.8	9.8	36.6	36.6	36.6	36.6
1	9.8	7.7	10.3	10.0	44.5	26.5	39.3	37.4
2	8.6	4.3	11.5	10.4	47.8	10.3	45.8	41.9

TABLE 1

Effects of N, P and K on the foliage growth (visual ratings and dry weights) of container grown *Erica carnea* 'Springwood White' (Experiment A). (*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

	Nutrients (g/m^3)	Visual ratings 6 months	Visual ratings 8 months	Dry Wt. (g/plt.)
N	45	4.22 ***	3.21 ***	7.63 ***
	450	3.60	4.16	15.22
P	30	3.96 -	3.52 **	11.33 -
	300	3.86	3.85	11.51
K	25	3.91 -	3.92 ***	12.12 **
	250	3.91	3.45	10.72
LSD (5%)		0.21	0.24	1.01
(P)	Significant Interactions			
NP		***	***	-
NK		***	-	#
PK		*	**	-
NPK		-	-	-
CV (%)		19	24	32

Additional Treatments (Experiment A)

Treat No.	Nutrients (g/m^3) N	P	K	Visual ratings 6 months	Visual ratings 8 months	Dry Wt. (g/plt.)
1	900	300	250	2.2 B c +	1.9 B b	9.5 B b
2	450	600	250	2.9 AB ab	2.5 AB ab	9.9 B b
3	450	300	500	2.3 B bc	2.1 B b	10.0 B b
4	900	600	500	0.4 C d	0.3 C c	0.7 C c
5	0	0	0	3.2 A a	2.0 B b	3.8 C c
6	450	300	250 ++	3.4 A a	3.1 A a	14.9 A a
C.V. (1)				46	57	50

(+ Duncan's letters given for means differing at the 1% (upper case) and 5% (lower case) levels of significance).

++ Based on slow release Osmocote (18/2.6/10)

TABLE 2

Interaction of N, P and K fertilisation on the foliage growth of *Erica carnea* 'Springwood White'.

Visual Ratings

6 months

	P_0	P_1
N_0	3.72	4.24
N_1	4.12	4.80

	K_0	K_1
N_0	4.44	3.44
N_1	3.36	3.16

LSD (5%) 0.30

8 months

	K_0	K_1
P_0	3.92	3.12
P_1	3.92	3.78

LSD (5%) 0.34

TABLE 3

Constants and coefficients of response surfaces for *Erica carnea* 'Springwood White' foliar ratings (7 months) and dry weights (central composite experiment): X_1 = nitrogen, X_2 = phosphorus, X_3 = potassium, X_4 = lime.

	Linear Terms		Quadratic Terms	
	Rating	Dry Wt	Rating	Dry Wt
Constant	0.336	19.303		
X_1	0.026 ***	7.286 ***	-0.017 **	-0.863 #
X_2	0.002	0.519	-0.006	-1.352 **
X_3	-0.002	-0.225	-0.000	0.426
X_4	-0.005	-1.626 **	-0.003	0.789

Cross Product Terms

	Rating	Dry Wt
X_1 X_2	-0.003	-0.484
X_1 X_3	-0.007	-0.795
X_1 X_4	0.006	-0.430
X_2 X_3	0.011	0.026
X_2 X_4	-0.008	0.193
X_3 X_4	0.005	0.557

	Rating	Dry Wt
S.E. Linear terms	0.01	0.52
S.E. Quadratic terms	0.01	0.49
S.E. Interactive terms	0.01	0.64
CV (%)	36	48
R^2 (%)	16	59

TABLE 4

Levels and rates of fertiliser for *Erica carnea* 'Springwood White' composite.

Level	Nitrogen g N/m^3	Phosphorus g P/m^3	Potassium g K/m^3	Lime kg/m^3
-2	0	0	0	0
-1	150	100	83	3
0	300	200	166	6
1	450	300	250	9
2	600	400	332	12

TABLE 5

Effects of N, P, K and Lime on the foliage growth (visual rating and dry weights - predicted values) of *Erica carnea* 'Springwood White'.

Visual Ratings At 7 Months

Level	Nitrogen	Phosphorus	Potassium	Lime
-2	2.2	3.1	3.4	3.3
-1	2.9	3.3	3.4	3.4
0	3.4	3.4	3.4	3.4
1	3.5	3.3	3.3	3.3
2	3.2	3.1	3.3	3.1

Mean Dry Wt. (g/plt.)

Level	Nitrogen	Phosphorus	Potassium	Lime
-2	1.3	12.9	21.5	25.7
-1	11.2	17.4	20.0	21.7
0	19.3	19.3	19.3	19.3
1	25.7	18.5	19.5	18.4
2	30.4	14.9	20.6	19.2

TABLE 6

Effects of N, P and K fertilisation on the foliar levels of 6 nutrients in *Erica carnea* 'Springwood White'.

Added Nutrients (g/m^3)		Foliar Analysis (g %) N	P	K	Mg	Ca	Na
N	45	1.18 ***	0.30 ***	1.25 ***	0.27 ***	0.61 ***	0.16 ***
	450	1.73	0.13	0.87	0.24	0.45	0.23
P	30	1.41 -	0.17 ***	1.02 #	0.25 -	0.49 **	0.20 -
	300	1.50	0.26	1.10	0.26	0.56	0.20
K	25	1.42 -	0.22 -	0.92 ***	0.26 -	0.52 -	0.20 -
	250	1.49	0.20	1.20	0.25	0.53	0.19
LSD (5%)		0.14	0.03	0.08	0.02	0.05	0.03
Significant Interactions							
(P)	NP	-	***	-	*	-	*
	NK	-	-	*	*	-	-
	PK	-	-	-	-	-	-
	NPK	-	-	*	-	-	-
CV (%)		15	20	12	12	14	27

Chapter seven

TABLE 7

Interaction of N, P and K fertilisation on foliar nutrients in *Erica carnea* 'Springwood White'.

Foliar Analysis (g%)

Foliar P

	P_0	P_1
N_0	0.21	0.40
N_1	0.13	0.13
LSD (5%)	0.03	

Foliar K

		K_0	K_1
N_0	P_0	1.02	1.34
	P_1	1.29	1.34
N_1	P_0	0.70	1.01
	P_1	0.68	1.09
LSD (5%)		0.16	

Foliar Mg

	K_0	K_1
N_0	0.27	0.28
N_1	0.26	0.21
LSD (5%)	0.03	

Foliar Na

	P_0	P_1
N_0	0.19	0.14
N_1	0.21	0.25
LSD (5%)	0.05	

Chapter eight

TABLE 1

Details Of Individual Trials

Expt	Plant Species	No. of Treatments	Reps. (plants/ treatment)	Method of Propagation	Dates Bagged	Dates Lifted
A	*Fatsia japonica*	14	10	seed	30.9.74	7.4.75
B	*Ficus elastica*	15	12	cuttings	7.11.74	3.10.75
C	*Dianthus chinensis* 'Dwarf Fragrance'	27	10	seed	14.2.75	19.5.75
D	*Tagetes patula* 'Sparky' (marigold)	14	15	seed	30.9.74	2.12.74
E	*Tagetes patula* 'Sparky'	30	14	seed	27.1.75	5.5.75

TABLE 2

Effects of N, P and K on the foliage growth (height and dry weight) of 4 container grown nursery plants.

(*** = P < 0.001; ** = P < 0.01; * = P < 0.05; # = P 0.05 - 0.10)

Experiments		A	B		
		Fatsia japonica	*Ficus elastica*		
Nutrient Levels (g/m³)		Dry Wt. (g/plt.)	Ht (cm)		Dry Wt. (g/plt.)
			6½ months	11 months	
N	45	9.9 *	27.8 ***	27.6 ***	28.0 ***
	225	-	-	-	-
	450	12.3	44.3	46.0	56.9
P	30	11.0 -	30.7 ***	29.5 ***	30.0 ***
	150	-			-
	300	11.1	41.4	42.2	54.8
K	25	10.4 -	35.1 -	36.0 -	38.0 **
	125	-	-		-
	250	11.7	37.1	37.7	46.8
LSD (5%)		1.9	5.4	5.6	6.5
(P)		Significant Interactions			
NP		-	*	**	***
NK		-	-	-	***
PK		-	-	-	-
NPK		-	-	-	*
CV (%)		38	37	37	38

Chapter eight

TABLE 2 contd.

Experiments		C	D
		Dianthus chinensis 'Dwarf Fragrance'	*Tagetes patula* 'Sparky'
Nutrient Levels (g/m³)		Dry Wt. (g/plt.)	Dry Wt. (g/plt.)
N	45	1.8 ***	1.2 ***
	225	3.3	-
	450	4.0	4.8
P	30	3.0 -	2.7 *
	150	3.0	-
	300	3.1	3.2
K	25	2.8 **	2.5 ***
	125	2.9	-
	250	3.3	3.4
LSD (5%)		0.3	0.48
(P)		Significant Interactions	
NP		-	-
NK		**	**
PK		-	*
NPK		*	-
CV (%)		36	44

TABLE 3

The interaction of nutrient levels on the foliage growth (height and dry weights) of *Ficus elastica*.

Mean height per plant (cm)

g nutrient/m^3		6½ months P 30	6½ months P 300	11 months P 30	11 months P 300
N	45	26.0	29.7	24.5	30.8
	450	35.4	53.2	34.5	57.6
LSD (5%)		7.6		7.6	

Mean dry wt. of foliage (g/plt

		P 30	P 300
N	45	21.5	34.4
	450	38.5	75.3
LSD (5%)		9.2	

		K 25	K 250
N	45	29.7	26.2
	450	43.3	67.5
LSD (5%)		9.2	

		K_0	K_1
N_0	P_0	20.1	23.0
	P_1	39.3	29.4
N_1	P_0	33.4	43.7
	P_1	59.3	91.3
LSD (5%)		13.0	

TABLE 4

The interaction of nutrient levels on the foliage growth (dry weights) of *Dianthus chinensis* 'Dwarf Fragrance' and *Tagetes patula* 'Sparky'.

Mean Dry Weight Of Foliage (g/plt.)

Dianthus

g nutrient/m^3		K 25	K 125	K 250
N	45	1.9	1.9	1.7
	225	2.8	3.3	3.6
	450	3.7	3.6	4.6
LSD (5%)		0.6		

Tagetes

		K 25	K 250
N	45	1.1	1.3
	450	4.0	5.6
LSD (5%)		0.7	

		K_0	K_1	K_2
N_0	P_0	2.1	1.8	1.8
	P_1	1.6	1.9	1.5
	P_2	2.1	2.1	2.0
N_1	P_0	2.7	2.4	3.8
	P_1	2.5	4.1	3.7
	P_2	3.1	3.5	3.6
N_2	P_0	4.1	3.7	4.3
	P_1	3.8	3.1	5.2
	P_2	3.2	4.1	4.3
LSD (5%)		1.0		

		K 25	K 250
P	30	2.6	2.9
	300	2.5	4.0
LSD (5%)		0.7	

TABLE 5

Effects of additional fertiliser treatments and media on the foliage growth (visual ratings, height and dry weights) of 3 container grown plants.

Treat No.	Nutrients (g/m³) N	P	K		Dry Wts. (g/plt.) *Fatsia japonica*	*Tagetes patula* 'Sparky'
1	450	300	250	SRO+	16.3 A a	3.2 a
2	625	400	361	SRO	10.7 A ab	4.1 a
3	900	600	500	SRO	13.1 A ab	3.5 a
4	225	150	125	PS	8.5 A b	3.8 a
5	225	150	125	FRO	14.1 A ab	3.5 a
6	450	300	250	PS	10.6 A ab	4.2 a
CV (%)					53	41

Ficus elastica

					Ht. (cm) 6½ months	11 months	Dry Wt. (g/plt
1	900	300	250	FRO	52.8 AB ab	57.5 A ab	72.8 AB ab
2	450	300	250	SRO	48.8 AB abc	52.3 AB ab	74.6 AB ab
3	900	300	500	SRO	48.4 AB abc	53.2 AB ab	79.8 AB ab
4	450	300	250	F	45.7 AB bc	45.3 AB bc	59.4 BC bc
5	900	300	360	F	38.7 B c	37.8 B c	43.8 C c
6	450	300	250	U	60.2 A a	60.8 A a	90.7 A a
7	900	300	250	U	53.1 AB ab	56.8 A ab	74.2 AB ab
CV (%)					28	28	36

+ SRO - Slow release NPK from 8 - 9 month Osmocote (18/2.6/10)

PS - Peat/sand (1:1, vv) plus fertilisers as per factorial experiments (all others peat/perlite).

FRO - Fast release NPK as per factorial experiments

F - Floranid Nitrophoska (20/2/7)

U - Uramite (38/0/0)

TABLE 6

Effects of N, P and K fertilisation on the foliar levels of 6 nutrients in 2 plant species.

($*** = P < 0.001$; $** = P < 0.01$; $* = P < 0.05$; $\# = P\ 0.05 - 0.10$)

Foliar Analysis (g%)

Ficus elastica

Added Nutrients (g/m³)		N	P	K	Mg	Ca	Na
N	45	0.53 **	0.17 -	1.26 ***	0.51 ***	1.80 -	0.04 *
	450	0.66	0.14	0.80	0.62	1.70	0.03
P	30	0.58 -	0.13 *	1.05 -	0.54 -	1.57 **	0.03 *
	300	0.61	0.18	1.01	0.59	1.93	0.04
K	25	0.64 -	0.16 -	0.78 ***	0.67 ***	1.84 -	0.03 -
	250	0.59	0.15	1.28	0.46	1.67	0.03
LSD (5%)		0.11	0.04	0.17	0.06	0.21	0.01

Significant Interactions

	N	P	K	Mg	Ca	Na
NP	-	-	-	-	-	-
NK	#	-	-	-	-	-
PK	-	-	-	-	-	-
NPK	-	#	-	-	-	-
CV (%)	25	37	25	16	18	24

TABLE 6 contd.

Tagetes patula 'Sparky' (marigold)

		N	P	K	Mg	Ca	Na
N	45	1.84 ***	0.42 **	3.08 **	0.94 ***	1.59 -	0.02 *
	450	4.30	0.49	2.59	1.42	1.54	0.08
P	30	2.90 **	0.33 ***	2.88 -	1.13 #	1.43 ***	0.04 -
	300	3.24	0.58	2.80	1.23	1.71	0.06
K	25	3.34 ***	0.47 #	1.94 ***	1.49 ***	1.78 ***	0.04 -
	250	2.80	0.43	3.73	0.86	1.36	0.06
LSD (5%)		0.24	0.04	0.33	0.10	0.10	0.05

Significant Interactions

NP	**	***	-	*	-	-
NK	**	-	-	***	-	-
PK	-	-	-	#	-	-
NPK	-	-	-	-	-	-
CV (%)	18	22	26	19	14	206

TABLE 7

Interaction of N, P and K fertilisation on foliar nutrients in *Tagetes patula* 'Sparky'.

Foliar Analysis (g%)

Tagetes patula 'Sparky' (marigold)

	Foliar N			Foliar P			Foliar Mg	
	P_0	P_1		P_0	P_1		P_0	P_1
N_0	1.87	1.82	N_0	0.36	0.48	N_0	0.95	0.92
N_1	3.93	4.66	N_1	0.30	0.69	N_1	1.31	1.53
	K_0	K_1					K_0	K_1
N_0	1.91	1.77				N_0	1.16	0.71
N_1	4.76	3.83				N_1	1.82	1.01
LSD (5%)	0.34			0.06			0.14	

TABLE 8

Constants and coefficients of response surfaces for *Tagetes patula* 'Sparky', dry weights (tops) (central composite experiment): X_1 - nitrogen, X_2 - phosphorus, X_3 - potassium, X_4 - lime.

Linear Terms		Quadratic Terms		Cross Product Terms	
Constant	6.773			$X_1 X_2$	- 0.075
X_1	1.167 ***	X_1	- 0.601 **	$X_1 X_3$	0.064
X_2	0.079	X_2	- 0.406 #	$X_1 X_4$	0.155
X_3	0.222	X_3	- 0.133	$X_2 X_3$	- 0.279
X_4	0.494 *	X_4	- 0.373 #	$X_2 X_4$	0.122
				$X_3 X_4$	- 0.108

S.E. Linear terms	0.23
S.E. Quadratic terms	0.22
S.E. Interactive Terms	0.29
CV (%)	77
R^2 (%)	21

TABLE 9

Levels and rates of fertiliser for marigold composite (Experiment E).

Level	Nitrogen g N/m^3	Phosphorus g P/m^3	Potassium g K/m^3	Lime kg/m^3
-2	0	0	0	0
-1	150	100	83	3
0	300	200	166	6
1	450	300	250	9
2	600	400	332	12

TABLE 10

Effects of N, P, K and Lime on the foliage growth (dry weights - predicted values) of *Tagetes patula* 'Sparky'.

Mean Dry Wt. (g/plt.)

Level	Nitrogen	Phosphorus	Potassium	Lime
-2	2.0	5.0	5.8	4.3
-1	5.0	6.3	6.4	5.9
0	6.8	6.8	6.8	6.8
1	7.3	6.4	6.9	6.9
2	6.7	5.3	6.7	6.3

TABLE 1

Details of individual trials.

Expt.	Plant Species	No. of Treats.	Reps. (plts./treat.)	Method of Propagation	Dates Bagged	Dates Lifted
A.	*Grevillea rosmarinifolia* A. Cunn	8	10	cuttings	4.10.73	16.9.74
	Protea scolymocephala Reichard			seed		
B.	*Camellia japonica* L.	8	10	seed	8.10.73	2.12.74
	Erica carnea 'Springwood White'			cuttings		23.9.74
	Hakea laurina R.Br.			seed		23.9.74
C.	*Grevillea* 'Olympic Flame'	4	10	cuttings	9.10.73	10.6.74
	Dryandra formosa R.Br.	4		seed		
D.	*Grevillea robusta* A. Cunn. ex R.Br.	7	10	seed	28.1.74	12.8.74
E.	*Grevillea robusta* A. Cunn. ex R.Br.	3	5	seed	28.1.74	28.1.75
	Grevillea rosmarinifolia A. Cunn.			cuttings		
	Leucadendron adscendens R.Br.			seed		
	Leucospermum candicans Loud.			cuttings		
	Protea repens (L.) L.			seed		
	Protea scolymocephala Reichard			seed		
F.	*Eucalyptus nicholii* Maiden & Blake	6	10	seed	13.6.74	20.11.74
	Eucalyptus notabilis Maiden	4	10	seed		

TABLE 2

Experiment A - Effect of 8 levels of N on foliage growth (visual ratings and dry weights) of 2 container grown nursery plants.

(*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$; # = P 0.05 - 0.10)

	Grevillea rosmarinifolia									*Protea scolymocephala*								
N Levels	Visual ratings						Dry Wt.			Visual ratings						Dry Wt.		
(g/m^3)	3 months			7½ months			(g/plt.)			3 months			7½ months			(g/plt.)		
0	3.3	A	a[+]	2.0	B	c	3.8	CD	c	4.2	A	a	2.7	B	b	7.9	BC	bc
45	-	-		-	-		-	-		4.4	A	a	4.3	B	a	12.7	B	b
110	4.1	A	a	4.0	A	a	34.5	A	a	3.8	A	a	3.6	B	ab	14.1	AB	b
225	3.3	A	a	3.5	A	ab	34.1	A	a	4.2	A	a	4.5	AB	a	9.7	BC	b
340	3.6	A	a	4.2	A	a	19.7	B	b	3.9	A	a	4.0	B	a	23.6	A	a
450	2.2	B	b	3.0	AB	b	15.4	BC	b	3.7	A	a	1.0	C	c	1.5	C	c
675	0.1	C	c	0	C	d	0	D	c	2.3	B	b	0.2	C	c	0	C	c
900	0.3	C	c	0.3	C	d	1.8	CD	c	1.3	B	b	0.1	C	c	0	C	c
(P)	***			***			***			***			***			***		
C.V. (%)	32			40			66			28			45			90		

+ In all Tables, Duncan's letters given for means differing at the 1% (upper case) and 5% (lower case) levels of significance.

TABLE 3

Experiment B - Effects of 8 levels of N on the foliage growth (visual ratings and dry weights) of 3 container grown nursery plants.

Camellia japonica

N Levels (g/m^3)	Visual ratings 2 months	7 months	11½ months	Dry Wt. (g/plt.)
0	3.6 a	1.3 C c	2.0 E e	0.4 C c
45	4.1 a	3.1 B b	3.0 D d	1.0 BC c
110	3.9 a	3.8 AB a	3.9 BC bc	2.0 ABC bc
225	4.0 a	4.1 AB a	4.1 ABC bc	3.5 A ab
340	4.0 a	3.9 AB a	3.6 CD cd	3.2 AB ab
450	4.2 a	4.0 AB a	4.0 BC bc	2.9 AB ab
675	4.3 a	4.8 A a	4.8 A a	4.2 A a
900	4.3 a	4.2 AB a	4.4 AB ab	4.4 A a
(P)	-	***	***	***
C.V. (%)	19	25	17	66

TABLE 3 contd.

Erica carnea 'Springwood White'

N Levels (g/m^3)	Visual ratings 2 months	7 months	11½ months	Dry Wt. (g/plt.)
0	3.6 a	2.0 A c	2.0 D d	4.2 C b
45	4.1 a	3.7 A b	2.9 C c	7.7 BC b
110	4.3 a	4.2 A ab	3.2 BC c	13.2 AB a
225	4.3 a	4.7 A a	3.9 AB b	15.9 A a
340	4.1 a	4.1 A ab	4.2 A ab	14.7 A a
450	4.2 a	4.2 A ab	4.6 A a	12.7 AB a
675	4.2 a	4.3 A ab	4.3 A ab	16.4 A a
900	4.0 a	4.0 A ab	4.4 A ab	13.5 AB a
(P)	-	***	***	***
C.V. (%)	18	19	16	36

TABLE 3 contd.

Hakea laurina

N Levels (g/m^3)	Visual ratings 2 months	7 months		11½ months		Dry Wt. (g/plt.)	
0	3.7 a	3.0 B	b	3.1 BC	cd	15.6 C	e
45	4.3 a	3.7 A	a	3.3 BC	bcd	24.9 BC	de
110	4.2 a	4.0 A	a	3.7 BC	bc	48.4 AB	c
225	4.4 a	4.2 A	a	4.1 AB	b	50.7 AB	c
340	4.1 a	4.3 A	a	4.9 A	a	73.2 A	ab
450	4.4 a	4.0 A	a	3.8 ABC	bc	53.1 AB	bc
675	4.2 a	4.6 A	a	4.0 AB	b	76.0 A	a
900	4.6 a	3.7 A	a	2.7 C	d	41.3 BC	cd
(P)	-	*		***		***	
C.V. (%)	16	24		23		47	

TABLE 4

Experiment C - Effects of N levels and type of fertiliser on the foliage growth (visual ratings and dry weight) of 2 container grown nursery plants.

	Dryandra formosa			*Grevillea* 'Olympic Flame'		
N levels (N) (g/m^3)	Visual ratings 2 months	7 months	Dry Wt. (g/plt.)	Visual ratings 2 months	7 months	Dry Wt. (g/plt.)
225	4.0 #	4.0 #	15.1 -	3.8 -	3.9 *	14.4 ***
450	3.7	3.7	14.3	4.0	4.3	22.2
Fertiliser (F)						
Uramite	4.3 ***	4.3 ***	19.6 ***	3.9 -	3.8 **	15.0 ***
Osmocote	3.4	3.4	9.8	3.9	4.4	21.6
LSD (5%)	0.3	0.3	4.0	0.4	0.4	3.3
(P)	Significant Interactions					
NF	-	-	-	-	-	**
CV (%)	11	11	42	18	14	28

TABLE 5

Experiment C - Interaction of nitrogen rate and type of fertiliser on the foliage growth (dry weights) of *Grevillea* 'Olympic Flame'.

		Uramite	Osmocote
N g/m^3	225	14.0	14.9
	450	16.0	28.3
LSD (5%)		4.6	

TABLE 6

Experiment D - Effects of 7 levels of N on the foliage growth (dry wts.) of container grown *Grevillea robusta*.

N Levels (g/m^3)	Visual ratings 3½ months			Dry Wt. (g/plt.)		
0	2.0	B	c	8.2	C	b
45	2.5	B	c	15.3	BC	b
110	3.7	A	b	29.5	AB	a
225	3.9	A	ab	33.7	A	a
340	4.4	A	ab	41.2	A	a
450	4.2	A	ab	42.0	A	a
675	4.5	A	a	42.0	A	a
(P)	***			***		
C.V. (%)	20			42		

TABLE 7

Experiment E - Effects of 3 levels of N on the foliage growth (visual ratings and dry weights) of 6 container grown nursery plants.

Plants	N Levels (g/m^3)		Visual ratings 3½ months			Visual ratings 8 months			Dry Wt. (g/plt.)		
Grevillea robusta	45		2.8	B	b	2.9	B	b	24.7	B	b
	225		4.2	AB	a	4.6	A	a	61.6	A	a
	450		4.6	A	a	4.2	AB	a	55.3	A	a
		(P)	*			*			**		
		CV(%)	22			17			27		
Grevillea rosmarinifolia	45		4.2	A	a	4.2	a		16.6	a	
	225		3.8	A	a	3.2	a		17.8	a	
	450		3.0	A	b	3.4	a		18.8	a	
		(P)	0.10			-			-		
		CV(%)	21			22			41		
Leucadendron adscendens	45		3.4	a		3.2	a		14.6	A	b
	225		3.8	a		3.8	a		20.2	A	ab
	450		4.4	a		4.0	a		23.2	A	a
		(P)	-			-			0.06		
		CV(%)	28			42			25		
Leucospermum candicans	45		4.0	a		4.6	a		31.9	a	
	225		3.4	a		3.8	a		25.2	a	
	450		4.4	a		4.0	a		32.6	a	
		(P)	-			-			-		
		CV(%)	26			33			53		

TABLE 7 contd

Plants	N Levels (g/m^3)	Visual ratings 3½ months	Visual ratings 8 months	Dry Wt. (g/plt.)
Protea repens	45	3.8 a	4.6 a	15.1 a
	225	3.4 a	3.0 a	19.5 a
	450	3.2 a	2.0 a	11.5 a
	(P)	-	-	-
	CV(%)	37	60	118
Protea scolymocephala	45	4.2 a	4.4 A a	23.5 a
	225	4.0 a	1.0 A b	6.3 a
	450	4.0 a	0.8 A b	8.1 a
	(P)	-	*	-
	CV(%)	19	80	110

TABLE 8

Experiment F - Effects of a range of N levels on the foliage growth (visual ratings and dry weights) of 2 container grown nursery plants.

N Levels (g/m^3)	*Eucalyptus nicholii* Visual ratings 2½ months	*Eucalyptus nicholii* Dry Wt. (g/plt.)	*Eucalyptus notabilis* Visual ratings 2½ months	*Eucalyptus notabilis* Dry Wt. (g/plt.)
0	2.2 B b	1.8 A c	1.5 B b	0.6 B c
110	3.2 AB a	11.4 A b	2.9 A a	11.6 B b
225	3.7 A a	17.4 A ab	-	-
340	3.7 A a	20.8 A a	3.1 A a	30.0 A a
450	3.4 AB a	21.4 A a	-	-
675	3.5 A a	21.3 A a	2.9 A a	31.5 A a
(P)	*	***	**	***
C.V. (%)	30	50	40	65

TABLE 1

Details of individual trials

Expt.	Plant Species	No. of Treatments	Reps. (plants/ treatment)	Method of Propagation	Dates Bagged	Dates Lifted
A	*Grevillea robusta* A. Cunn. ex R. Br.	3	5	seed	30.1.74	28.1.75
	Grevillea rosmarinifolia A. Cunn.			cuttings		
	Leucadendron adscendens R. Br.			seed		
	Leucospermum candicans Loud.			cuttings		
	Protea repens (L.) L.			seed		
	Protea scolymocephala Reichard			seed		
B	*Banksia spinulosa* Sm.	5	10	seed	22.1.74	12.8.74
	Dryandra formosa R. Br.			seed		
	Telopea speciosissima R. Br.			seed		
C	*Camellia japonica* L.	10	10	seed	1.8.73	7.4.74
	Erica carnea L. 'Springwood White'			cuttings		
	Grevillia rosmarinifolia A. Cunn.			cuttings		
	Hakea laurina R. Br.			seed		
	Protea repens (L.) L.			seed		
D	*Protea scolymocephala* Reichard	36	7	seed	5.11.73	15.5.74

TABLE 2

Expt A - Effects of 3 levels of P on the foliage growth (visual ratings and dry weights) of 6 container grown nursery plants.

(*** = P < 0.001; ** = P < 0.01; * = P < 0.05; # = P 0.05 - 0.10)

Plants	P Levels (g/m^3)		Visual ratings $3\frac{1}{2}$ months	Visual ratings $7\frac{1}{2}$ months	Dry Wt. (g/plt.)
Grevillea robusta	15		3.8 a	3.4 a	41.8 a
	30		4.0 a	3.8 a	42.9 a
	120		4.0 a	4.4 a	53.4 a
		(P)	-	-	-
		C.V. (%)	14	25	37
Grevillea rosmarinifolia	15		3.4 A a	4.2 A a	15.0 A a
	30		3.2 A a	4.6 A a	12.9 A a
	120		1.6 A b	1.6 B b	4.6 B b
		(P)	*	**	**
		C.V. (%)	32	29	34
Leucadendron adscendens	15		3.4 A a	3.2 a	14.5 A a
	30		3.8 A a	3.6 a	14.6 A a
	120		1.8 A b	1.8 a	4.7 A b
		(P)	*	-	*
		C.V. (%)	31	50	51
Leucospermum candicans	15		3.8 a	4.0 a	20.2 a
	30		4.0 a	4.4 a	32.3 a
	120		3.8 a	4.1 a	27.9 a
		(P)	-	-	-
		C.V. (%)	27	28	67

TABLE 2 contd.

Plants	P Levels (g/m³)		Visual ratings 15.5.74 3½ months	23.9.74 7½ months	Dry Wt. (g/plt.)
Protea repens	15		4.0 A a	2.6 AB a	11.7 a
	30		4.4 A a	4.3 A a	16.2 a
	120		0.2 B b	0 B b	7.3 a
		(P)	**	**	-
		C.V. (%)	41	53	140
Protea scolymocephala	15		3.8 A a	3.6 A a	12.9 a
	30		3.4 A a	3.0 A a	10.6 a
	120		0 B b	0 B b	0 a
		(P)	**	**	-
		C.V. (%)	46	51	194

TABLE 3

Experiment B - Effects of 5 levels of P on the foliage growth (visual ratings and dry weights) of 3 container grown nursery plants.

P Levels (g/m³)	*Banksia spinulosa* Visual rating 3½ months	*Banksia spinulosa* Dry Wt. (g/plt.)	*Dryandra formosa* Visual rating 3½ months	*Dryandra formosa* Dry Wt. (g/plt.)
0	2.9 AB ab	3.1 A a	3.8 A a	13.5 AB a
15	3.3 A a	1.5 AB ab	3.2 A a	12.7 AB a
30	1.8 AB bc	0.5 B b	3.5 A a	20.8 A a
60	1.5 BC c	0.1 B b	1.1 B b	4.5 BC b
120	0.1 C d	0 B b	1.1 B b	0 C b
(P)	***	**	***	***
C.V. (%)	65	142	44	85

Telopea speciosissima

P Levels (g/m³)	Visual rating 3½ months	Dry Wt. (g/plt.)
0	3.7 AB ab	6.5
15	4.1 A a	6.5
30	3.0 AB bc	7.4
60	2.4 BC c	1.0
120	1.3 C d	0
(P)	***	***
C.V. (%)	35	53

TABLE 4

Expt C - Effects of 10 levels of P on the foliage growth (visual ratings and dry weights) of 5 container grown nursery plants.

Camellia japonica

P Levels (g/m^3)	Visual ratings 1½ months	2½ months	5 months	Dry Wt. (g/plt.)
50	4.5 a	3.8 A a	4.8 A a	12.3 A a
75	4.4 a	3.2 AB abc	4.4 A ab	11.2 AB ab
100	3.9 a	3.3 AB abc	3.9 A c	7.3 AB bc
125	3.9 a	3.0 AB c	4.4 A abc	8.3 AB abc
150	3.8 a	3.1 AB bc	4.3 A abc	6.4 B c
175	3.9 a	3.2 AB abc	4.4 A abc	8.1 AB abc
200	4.3 a	3.5 AB abc	4.6 A abc	9.5 AB abc
225	3.9 a	3.5 AB abc	4.5 A abc	10.3 AB abc
250	4.0 a	3.7 AB ab	4.7 A ab	12.6 A a
300	3.8 a	2.9 B c	4.0 A bc	8.8 AB abc
(P)	-	*	-	*
C.V. (%)	21	19	16	46

Erica carnea 'Springwood White'

P Levels (g/m^3)	Visual ratings 1½ months	2½ months	5 months	Dry Wt. (g/plt.)
50	3.4 A ab	3.2 a	4.0 AB abcd	18.7 B b
75	2.9 AB abc	3.2 a	3.6 AB d	17.2 B b
100	3.4 A ab	3.1 a	4.6 AB ab	38.9 A a
125	3.2 AB ab	3.3 a	4.7 A a	41.3 A a
150	3.2 AB ab	3.2 a	4.5 AB abc	21.3 B b
175	3.1 AB abc	3.0 a	3.8 AB bcd	15.6 B b
200	3.5 A a	3.2 a	3.7 AB cd	14.7 B b
225	2.6 B c	3.2 a	3.9 AB abcd	21.4 B b
250	2.8 AB bc	3.0 a	3.7 AB cd	19.4 B b
300	2.9 AB abc	2.7 a	3.5 B d	22.4 B b
(P)	*	-	**	***
C.V. (%)	19	23	21	40

TABLE 4 contd.

Grevillea rosmarinifolia

P Levels (g/m^3)	Visual ratings 1½ months	2½ months	5 months	Dry Wt. (g/plt.)
50	4.1 AB a	4.5 A a	4.8 AB ab	39.5 ABC abc
75	4.2 A a	4.5 A a	5.0 A a	45.1 A a
100	4.2 A a	4.2 A a	3.7 BC cd	20.0 DE f
125	3.1 C b	3.3 B b	4.5 ABC abc	21.9 E ef
150	3.2 BC b	2.7 BC bc	4.1 ABC abcd	30.7 BCDE cde
175	2.7 C b	2.4 BC c	4.1 ABC abcd	26.5 DE def
200	3.3 ABC b	3.2 B b	3.8 ABC cd	42.7 AB ab
225	3.1 C b	2.9 BC bc	3.9 ABC bcd	34.6 ABCD bcd
250	3.0 C b	2.2 C c	3.5 C d	31.1 BCDE cde
300	2.7 C b	2.4 Bc c	3.4 C d	27.1 CDE def
(P)	***	***	**	***
C.V. (%)	23	22	23	40

Hakea laurina

P Levels (g/m^3)	Visual ratings 1½ months	2½ months	5 months	Dry Wt. (g/plt.)
50	4.3 A a	4.2 A a	4.8 A a	32.2 A a
75	2.5 B b	2.3 B b	4.1 AB ab	16.2 B b
100	2.1 BC bc	1.4 BC c	3.3 BC bc	8.6 C c
125	2.0 BCD bc	1.1 CD cd	2.5 CD cd	3.8 CD cd
150	1.5 CD cd	0.6 CD de	1.8 DE de	3.3 CD cd
175	1.1 D d	0.6 CD de	1.0 EF ef	1.4 CD d
200	1.7 BCD cd	0.7 CD cde	1.2 EF ef	1.6 CD d
225	1.1 D d	0.7 CD cde	0.9 EF ef	1.0 D d
250	1.5 CD cd	0.8 CD cde	0.9 EF ef	0.4 D d
300	1.1 D d	0.3 D e	0.4 F f	0 D d
(P)	***	***	***	***
C.V. (%)	39	61	46	83

TABLE 4 contd.

Protea scolymocephala

P Levels (g/m^3)	Visual ratings 1½ months	2½ months	5 months	Dry Wt. (g/plt.)
50	4.7 A a	4.2 A a	3.6 A a	14.3 A a
75	4.0 AB ab	1.5 B b	0.3 B c	0 B b
100	4.7 A a	1.5 B b	1.2 B b	3.5 B b
125	3.8 AB ab	0 C c	0 B c	0 B b
150	3.1 B b	0 C c	0 B c	0 B b
175	3.0 B b	0 C c	0 B c	0 B b
200	0.8 C c	0 C c	0 B c	0 B b
225	1.5 C c	0 C c	0 B c	0 B b
250	1.0 C c	0 C c	0 B c	0 B b
300	0.6 C c	0 C c	0 B c	0 B b
(P)	***	***	***	***
C.V. (%)	46	102	182	378

TABLE 5

Expt D - Effects of P, medium and lime on the foliage growth (visual ratings and dry weights) of container grown *Protea scolymocephala*.

		SMALL PLANTS			LARGE PLANTS		
		Visual ratings		Dry Wt.	Visual ratings		Dry Wt.
		3 months	6 months	(g/plt.)	3 months	6 months	(g/plt.)
	P (g/m^3)						
	15	3.3 -	3.5 -	10.6 -	3.9 #	4.3 **	20.3 -
	30	3.5	3.3	11.1	3.8	4.2	21.2
	60	3.3	3.5	10.9	3.6	3.8	18.7
LSD (5%)		0.3	0.4	2.0	0.2	0.3	2.5
	MEDIUM (M)						
	P:P	3.8 ***	4.0 ***	14.2 ***	4.3 ***	4.6 ***	25.6 ***
	P:P:Soil	3.0	2.9	7.5	3.2	3.6	14.5
LSD (5%)		0.2	0.3	1.7	0.2	0.2	2.1
	LIME (L) (kg/m^3)						
	3	3.5 -	3.5 -	11.2 -	3.7 -	4.0 -	18.0 **
	6	3.4	3.6	10.4	3.8	4.2	20.1
	12	3.2	3.3	10.9	3.8	4.2	22.1
LSD (5%)		0.3	0.4	2.0	0.2	0.3	2.5
(P)	Significant Interaction						
	PM	-	-	-	**	-	*
	PL	**	-	*	*	*	***
	ML	-	-	-	-	-	-
	PML	**	***	*	*	-	-
CV (%)		21	27	44	14	16	29

TABLE 6

The interaction of P, lime and media on the foliage growth (visual ratings and dry weight) of small grade *Protea scolymocephala* plants.

Visual ratings - 3 months

P (g/m^3)	Lime (kg/m^3) 3	6	12
15	3.9	3.1	2.9
30	3.3	3.6	3.6
60	3.4	3.3	3.2
LSD (5%) =		0.4	

		Visual ratings - 3 months: Lime (kg/m^3) 3	6	12	Visual ratings - 6 months: Lime (kg/m^3) 3	6	12
P (g/m^3) 15	PP	4.1	3.7	3.3	4.6	4.0	4.0
	PPS	3.7	2.6	2.6	3.1	2.7	2.9
30	PP	4.0	4.3	3.4	3.9	4.6	2.6
	PPS	2.6	3.0	3.7	2.4	2.7	3.9
60	PP	3.8	3.6	3.9	4.3	3.7	4.3
	PPS	3.0	3.0	2.6	2.6	3.7	2.1
LSD (5%) =			0.7			1.0	

Dry Wt. (g/plt.)

P (g/m^3)		Lime (kg/m^3) 3	6	12
15	PP	15.4	12.8	11.3
	PPS	12.4	5.5	6.0
30	PP	12.7	17.9	13.7
	PPS	6.6	5.2	10.3
60	PP	14.0	12.8	17.5
	PPS	6.4	8.0	6.7
LSD (5%) =			5.0	

P (g/m^3)	Lime (kg/m^3) 3	6	12
15	13.9	9.2	8.7
30	9.6	11.5	12.0
60	10.2	10.4	12.1
		2.9	

TABLE 7

The interaction of P, lime and media on the foliage growth (visual ratings and dry weight) of large grade *Protea scolymocephala* plants.

P (g/m^3)	Visual ratings - 3 months: Lime (kg/m^3) 3	6	12	Visual ratings - 6 months: Lime (kg/m^3) 3	6	12
15	4.1	3.9	3.7	4.4	4.4	4.2
30	3.6	3.8	4.1	3.7	4.3	4.6
60	3.6	3.8	3.4	3.8	3.9	3.7
LSD (5%) =		0.4			0.5	

Visual ratings - 3 months

P (g/m^3)		Lime (kg/m^3) 3	6	12
15	PP	4.3	4.1	4.4
	PPS	3.9	3.6	3.0
30	PP	4.0	4.4	4.3
	PPS	3.1	3.1	3.9
60	PP	4.3	4.6	4.2
	PPS	2.9	3.0	2.7
LSD (5%) =			0.6	

Dry Wt. (g/plt.)

P (g/m^3)	Lime (kg/m^3) 3	6	12
15	21.7	20.4	18.7
30	16.3	18.5	28.7
60	16.0	21.4	18.8
		4.4	

P (g/m^3)	Visual rating - 3 months: Media PP	PPS	Dry Wt. (g/plt.): Media PP	PPS
15	4.3	3.5	26.0	14.5
30	4.2	3.4	25.1	17.3
60	4.4	2.9	25.8	11.7
LSD (5%) =	0.3		3.6	